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Green hydrogen in Latin America

Possibilities, barriers and opportunities

Heloisa Schneider

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Foreword

It has been 27 years since the attempt by the then head of the World Environment Fund, Mohammed T El Ashry, to help implement the use of hydrogen in public transport systems by adding together the demand from several cities in order to attain a sufficient scale. That effort failed to implement the technology. During the time elapsed, one generation, the climate emergency has worsened. The concentration and the continued flow of greenhouse-effect gases have left a global carbon budget for a decade of inertial behavior.

In the same time span, the costs of electric generation with renewable sources have been dropping considerably and they are expected to continue to do so, along with battery prices. The price of water electrolyzers for the production of hydrogen has been dropping as well, while their generation capacity increases. Thus, as pointed out in the text, with green hydrogen, a convergence occurs among the technical capacity, the economic viability and the articulation among sectors that have been insulated from each other within the petroleum paradigm. This also takes place in a context of a marked volatility in the prices of fossil fuels, which contributes to the instability of the economies.

With these changes and their management, green hydrogen is becoming a technologically and economically viable alternative with an increasing potential as a deposit of renewable energy. This not only allows it to stabilize and deconcentrate the electricity supply grids: it also allows it to be applied to uses where the options of traditional electrification are not efficient: heavy, air and maritime, "off road" or machinery and railway forms of transport. Green hydrogen is thus becoming a key option for a climate action that is capable of helping in the decarbonization of sectors that have been difficult to approach thus far.

The generalized adoption of hydrogen, and green hydrogen in particular, will modify the global energy geopolitics. In a more or less remote future, the concentrated and unequal location of fossil hydrocarbons on the planet, the dispute for access to them, as well as their control and transport, will no longer be a critical axis in international relations. Moreover, the massification of green hydrogen may change the relative energy wealth or poverty of developing countries, since, save for rare exceptions, they are, for the most part, generously endowed with renewable energy sources. Countries that were previously poor in fossil hydrocarbons and subject to the volatility of their prices in the international market and to the weight of their respective oil bills, could now be energy-self-sufficient with green hydrogen or could even have a potential for export. Countries in Latin America and the Caribbean have in green hydrogen an enormous potential for adding on a more robust development, while, at the same time, strengthening their climate action to the extent that they fully engage in the expansion of their production, storage and use capacities. It is a new potential source of foreign currency income and jobs, with a smaller environmental footprint; precisely the characteristics of the sectors for a more sustainable development and within our planet's capacity to support it.

This book responds to the growing interest in ECLAC on the part of the Konrad Adenauer Foundation and several countries in the region on this issue, considered as crucial for development. Hence, this publication is most opportune. It is in Spanish and it contains data from the region, thoroughly researched by Heloisa Schneider. For the public in general and for Spanish-speaking technicians, the content of this text documents options for development that can materialize in their economies with the threefold dividend of achieving economic dynamism with a greater energy independence, more social inclusion, new jobs, and achieving at the same time the reduction of greenhouse-effect-gas emissions; aspects which, if achieved at the same time, allow us to get closer to fulfilling Agenda 2030.

The text allows us to learn about the advances and policies for the development of hydrogen economy in five countries of Latin America and the Caribbean, and to have a current, pertinent and useful notion for the region. The challenge, as others, is that this transformation in the energy paradigm be accompanied by a vision of caring for the planet and the people who inhabit it, in a spirit of increased fraternity.

José Luis Samaniego
Director of the Sustainable Development and Human Settlements Division

Economic Commission for Latin America and the Caribbean, ECLAC

01 | Introduction

Green hydrogen (H_2) has the potential, together with other measures, for contributing significantly to the greenhouse effect emissions reduction processes, and for creating a new industry that adds value to the economies of the countries. It is an alternative energy resource that can be used instead of coal, natural gas or oil. Its use can help countries to meet their emission reduction goals, and its fabrication, aside from generating jobs, can contribute to the GDP. This is especially the case in countries that do not produce and/or depend on fossil fuels, and that, at the same time, have clean energy sources for its fabrication, and water. But, in spite of the above, this issue has only very recently started to become part of the debates on alternative energies, and we still do not have much information on the possibilities of its massification as a source of energy and of income in the region. Moreover, there are some elements that must be taken into account in order to make viable this gas as an energy, which, if they are confronted early and adequately, can make this new wave of interest permanent, with the positive consequences that this implies.

Photography by Karsten Würth, source: www.unsplash.com

If, on the one hand, the low environmental impact of the energy generated by hydrogen is its best allied, on the other hand, the cost of obtaining it and the infrastructure, including for its transport, storage and distribution, are its greatest enemies. In order for hydrogen to be a reality, one kilogram, must cost half of the value of that of a gallon of gasoline, an amount that is still far from being reached. For green H_2, the renewable energy that will allow to produce it must cost less than 30 dollars/MWh. This hydrogen is still 2 to 3 times more expensive than the blue one and, in order for it to gain space, its costs must suffer important reductions, which must also include the corresponding infrastructure (IRENA, 2020), in order to unseat natural gas (NG), the main energy resource used in its production and, at the same time, one of the energy sources that is most widely used for the production of electricity in several countries. Once the issue of the high cost of production of the gas is solved, the focus will shift to fuel cells and to other technologies that can support this new industry.

But the cost is not the only barrier to its massification. Indeed, it may be the least complex one. Rather, there are even more difficult problems that must be solved as soon as possible, and which are associated with the risks related to the characteristics of this gas, regarding the environment, climate change, health and safety, as well as institutional and regulatory risks. The massification of its use requires that there be no competition among the sectors for the use of electricity from renewable energy sources, nor from water, the main element in the production of green H_2.

Nowadays, hydrogen is already relevant in economic terms. The world market in 2019 represented between 118 and 136 billion dollars. We also expect a significant growth of this market in the coming years that could reach between 160 to 200 billion dollars. The driving force behind this growth and this new wave is due to the fact that governments and businesses understand the role of hydrogen as a decarbonizing agent for the global economy and for the achievement of the objectives of the Paris Accord by the 2050 horizon.

In the last decade, the world demand for hydrogen grew by 28%, which is little in comparison to other new energy technologies. The production of ammonia for fertilizers and the refining of oil represented 96% of the raw demand, while from the demand for mixes with other gases the production of methanol represented 29%, the direct reduction in the steel industry represented 7%, and the rest was used in other areas (IEA, 2019). In transport, the participation is quite reduced. Almost nil.

Thus, aside from the already traditional markets of fertilizers, refining and other uses (industrial and hospital gases), new hydrogen markets can be developed in the segments of transport, generation of electricity, energy storage and industrial processes, among others. Hydrogen can be used directly as a source of energy with low or zero carbon (depending on its production process) in sectors that are difficult to electrify and as a vector for energy storage, allowing a greater contribution from variable renewable sources, such as wind, solar, etc. In this respect, hydrogen is regarded as a resource that has the ability to promote the coupling of the fuel, electrical, industrial and other markets.

Understanding that these issues are also material in the countries of Latin America, the Konrad Adenauer Foundation (KAS) has decided to publish this study, whose objective is to describe and analyze the possibilities for the massification of hydrogen as a source of energy resource in some countries of the region.

The study analyzed the barriers and opportunities from the current state and the advances on this issue in Argentina, Brazil, Chile, Costa Rica and Mexico, countries that currently have great possibilities to develop a competitive green hydrogen industry, to leverage and reply the opportunities and capabilities already developed in other regions and, at the same time, to be driving forces for this resource in the other countries of the region.

In these five countries, green hydrogen, to a greater or smaller extent, started to be considered as a business alternative and one more way of reducing greenhouse-effect gases. In some of them, it is considered as an important element for complying with the carbon-neutrality commitments. Its advantages for delving into this market are centered, above all, on its electrical matrices, which are either already clean or are on their way to decarbonizing. These advantages are opportunities in and of themselves, which give rise to others. But, in order to take advantage of them, some pitfalls must be solved rapidly and effectively, which could otherwise become a barrier that hinders the takeoff of this industry and/or its continuity: formalizing H_2 within the political, institutional and legal framework, including it on the public agendas and making room for, and supporting, the private sector, building a regional agenda and leveraging synergies in order to increase competitiveness.

The current moment is very propitious for the countries to define new business models for creating new markets, partnering and cooperating with countries such as Germany, Japan or the United States, where hydrogen economy is more advanced. Through these relationships, they may accelerate their internal processes and taking earlier advantage of this fuel. Building relationships with these countries allows not only to reduce and minimize costs, but, also, having a state-of-the-art technology, financing sources, trained manpower, and operating in more competitive markets, to mention only a few advantages.

As can be observed throughout the text, initiatives of this type are already underway and the potential of the region for continuing to advance and turning into a world-class player in this field becomes manifest. Thus, this document seeks to be a contribution to the debate over the introduction of green H_2 in the region and a meeting point. Therefore, we hope that the readers will use it as a reference and as an input.

Good reading.

Heloisa Schneider and the Regional Programme EKLA

02 | Hydrogen as an energy alternative

As a source of energy and fuel, H_2 offers ways for decarbonizing an ample range of sectors, including transport, chemical products, iron and steel, and other sectors where it has been difficult to significantly reduce emissions. It can also help to improve air quality and strengthen energy security. It can be transformed into electricity and methane to be used as domestic energy and feed the industry with fuel for automobiles, trucks, ships and airplanes, for example. Hence, the sectors where its use is contemplated depend to a great extent on the possibilities to mitigate not only its costs, but others, inherent to each sector which will have to adapt to this new energy.

Under normal pressure and temperature conditions, hydrogen exists as a diatomic gas (H_2) that is colorless, odorless, tasteless and nontoxic. It is estimated to be found in 75% of the visible matter in the universe and it is abundant on the planet, where, although it does not exist in a free state, it forms part of the most important molecules for life. As it is a very light element, it can escape the earth's atmosphere and, therefore, it is not found in its natural state. Its calorific power, which varies from 120 MJ/kg to 141 MJ/kg, is the highest among commonly used fuels (Estrada et al, 2020).

It contains more energy per mass unit than natural gas or gasoline, which makes it attractive as a fuel for transport. However, since it is the lightest element, it has a lower energy density per unit of volume. This means that greater volumes must be moved in order to satisfy similar energy demands in comparison to other fuels. And, in order to achieve it, it is necessary to have larger ducts or ducts with a faster flow and larger storage tanks. Hydrogen can be compressed, liquefied or transformed into hydrogen-based fuels that have a greater energy density. But this (and any later conversion) consumes energy, which is an important limitation for its manufacture.

Just as other energies, hydrogen poses risks to health and safety when used at a large scale and these risks can slow down or even limit its deployment as an energy technology. Safety in its use in its gaseous or liquid form and, especially in its transport, storage and distribution, is probably the greatest challenge to be faced in order to intensify its use. But, if one considers that the impacts on health and safety from the established energies (gasoline, diesel, natural gas, electricity, coal) are familiar for consumers and are rarely questioned, this shows that the risks from hydrogen, including flammability, the presumed carcinogenicity and toxicity, can be perfectly handled and will be internalized without problems inasmuch as it starts to be massified (IEA, 2019).

Despite the fact that there is ample experience in the industrial use of hydrogen, including in large dedicated distribution pipes and that there are protocols for its safe use in these places and for the replenishment infrastructure, massifying its use is still a complex task that will demand advancing in fields yet unknown in comparison to those of other energy carriers. Its generalized use within the energy system will bring new challenges and an important part of this process shall be to communicate adequately about the limitations and advantages of this new energy resource.

Its generalized use within the energy system will bring new challenges and an important part of this process shall be to communicate adequately about the limitations and advantages of this new energy resource.

As a method of production of green H_2, although today it is not used massively at the industrial level, water electrolysis is one of the technologies used for decomposing H_2O into oxygen (O_2) and hydrogen (H_2). However, as indicated by academics from the National Academy of Sciences of Costa Rica[1], some aspects of this process that are often not mentioned must be considered when deciding on its use in the manufacture of H_2: it is intensive in the use of electricity since water is a very stable substance and, moreover, in general, it is only considered that the end-product of the use of hydrogen in a fuel cell is water vapor and not the other atmospheric gases that contribute to the greenhouse effect and to global warming (CO_2, methane and others). If the water electrolysis process were to occur at 25ºC and one atmosphere of pressure, the energy consumption would be equivalent to 39,7 kWh per each kilogram of H_2 produced. This energy cost would be equivalent to the consumption of electrical energy for almost five days for a family using 250 kWh per month. This figure does not take into account the degrees of (in)efficiency implied by the actual electrochemical process and the equipment used, basically by the dissipation of electrical energy as heat and electrical overpotential. The figure does not take into account, either, the high cost of compressing the hydrogen for its storage or leaks, nor those related to transport. Nor does it take into account the costs of the substances for the prior chemical conditioning of the water required by industrial electrolysis, as well as that of other substances employed in this electrochemical process and the wear of electrodes and membranes. And, generally speaking, the needs in terms of water, its main supply, are not mentioned. Producing one kilo of hydrogen requires an average of between 10 to 12 liters of water. Half of this water input is returned, though with a greater degree of conductivity[2] , which limits its reuse.

1 Water electrolysis. Approach regarding the production and use of hydrogen as a driving force in the transport sector in Costa Rica. At https://www.anc.cr/vernoticias/118-electrolisis-del-agua-planteamiento-en-torno-a-la-produccion-y-uso-de-hidrogeno-como-ente-motriz-en-el-sector-transporte-en-costa-rica

2 Approximate indication of the degree of mineralization of the water

2.1 What are the meanings of hydrogen colors?

The reference to colors, a nomenclature increasingly used for categorizing hydrogen, derives from the sources used for its production. According to the International Energy Agency (IEA), the mention of “black”, “grey” or “brown” refers to the production of hydrogen from coal, natural gas and lignite, respectively. The color “blue” is commonly used in order to identify the hydrogen produced from fossil fuels with CO_2 emissions mitigated and reduced by the use of capture methods and the utilization and storage of carbon (CAC[3]). The color “green” applies to the hydrogen produced from the electricity generated with clean or renewable sources. In general, there are no colors established for hydrogen from biomass, nuclear or different varieties of the electric grid. It is worth mentioning that the IEA avoids using these labels as it estimates that the environmental impact from production can vary much within the same color category (IEA, 2019).

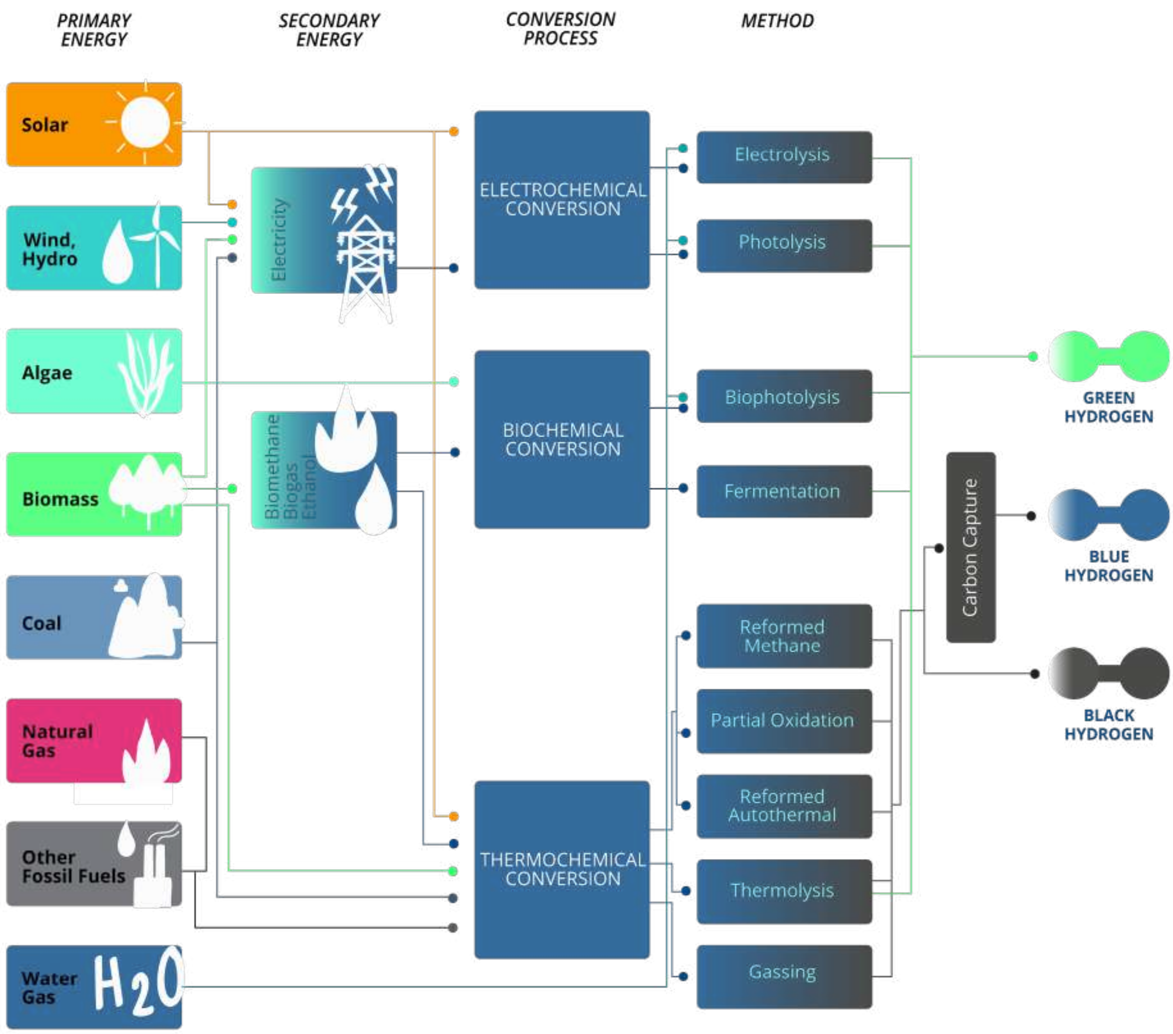
The hydrogen with low carbon emissions, that is to say, the green and blue, includes the hydrogen produced with nuclear and renewable electricity, biomass and fossil fuels with CAC, provided that the emissions upstream are sufficiently low, that the CO_2 capture applies to all of the CO_2 associated and that it is prevented from reaching the atmosphere. The same principle applies to the fuels and raw materials based on hydrogen with low carbon content and manufactured with low-carbon hydrogen.

Currently, less than 0,7% of hydrogen production comes from green or blue supplies produced on plants with carbon capture and low carbon emissions. For all the rest, natural gas and coal are used: 76% and 23% respectively; the latter mainly from China, and only 2% from electrolysis (IEA, 2019). According to data from the International Energy Agency (2019), 6% of the world production of natural gas and 2% of that of coal is destined for the production of hydrogen.

3 Capture, utilization and storage of carbon, CAC = CCUS: capture, utilization, and storage:

Each of these hydrogens has a different energy efficiency, which varies according to the fuel used and to the technology used for its production. Given that this technology requires much electricity, even with a lower efficiency, switching to clean energy sources such as solar or wind, would easily turn it into green, and could occupy spaces where natural gas is, for example, scarce, where it depends on imports or is very expensive or, in economies where the emission reduction strategies do not contemplate this gas to be a transition energy but, rather, as a fossil fuel whose use must be limited or eliminated from its energy matrix. Diagram 1 accounts for the different production processes for green, blue and black hydrogens.

Diagram 1. Simplified scheme of the production processes of green, blue and black hydrogens.



Source: https://www.h2chile.cl/produccion-del-h2?lightbox=dataItem-jrjm6ve

2.2 Hydrogen uses: current use and future perspectives in Latin America

In Latin America, hydrogen production and use are limited to some countries and, as in most of the world, it is mainly used as a raw material for refineries and the chemical industry.

In Chile, the hydrogen produced is mainly used for refinery processes and in other applications, in food and other special processes, but in smaller volume. The greatest use in refineries is for hydrotreatment or hydrocracking[4] and desulfurization of fuels. The Chilean commercial production is based on the technology for reforming methane gas with vapor. They use as their main supply natural gas from the grid and naphtha and liquefied gas from oil as secondary supplies. (GIZ, 2018).

In Mexico[5], the production base is natural gas and, to a smaller degree, propane. For the most part, H_2 is generated through the catalytic reformation of hydrocarbons and, to a lesser degree, through hydrolysis. The main use is found in the industrial sector.

In Brazil, its use is mostly industrial and an important part of it is used for the manufacture of ammonia, a basic component of agricultural fertilizers. This is also the case in Argentina.

It is estimated that the demand for products derived from hydrogen, particularly for refined fuels for transport, fertilizers for the food production and construction materials will continue to grow, so the contribution from hydrogen as a reducer of emissions from these production processes is increasingly visible. But aside from its

4 Decomposition of a substance into simpler components in the presence of hydrogen.

5 At http://www.ptolomeo.unam.mx:8080/xmlui/bitstream/handle/132.248.52.100/4711/tesis.pdf?sequence=1

costs, which are still high, although the gaps related to other energies have been reducing, a key issue for expanding its use and unleashing competitiveness in other applications is the availability of large-scale supply and distribution systems.

The Hydrogen Council, 2020, analyzed the competitiveness in terms of costs for 35 applications, 40 hydrogen technologies in four sectors; transport, buildings, industrial heat and industrial raw materials. The study included new and existing applications that are currently responsible for 60% of global greenhouse effect gas emissions related to the energy and the processes.

Among the applications analyzed, in 22 of them hydrogen can become a low-carbon and cost-competitive solution before 2030 in adequate conditions.

Among the applications analyzed, in 22 of them hydrogen can become a low-carbon and cost-competitive solution before 2030 in adequate conditions. In total, these applications represent 15% of the world's consumption of energy (17.500 TWh). This does not imply that this gas is going to satisfy all this demand for energy by 2030, but it does demonstrate that it is expected to play an important role as a vector of clean energy in the future energy combination.

These are examples of the applications whose total cost of ownership, TCO[6], according to the Hydrogen Council (2020) will reach parity with other low-carbon alternatives by 2030:

- Commercial vehicles, regional trains and long-haul transport will compete with the low-carbon alternatives due to the lower costs of equipment and fuel replenishment.
- Hydrogen boilers will be a competitive alternative for heating in buildings with low carbon emissions, especially for the existing ones that are served by natural gas.

6 TCO = Total Cost of Ownership, which reflects not only the cost of purchase but also aspects of use and maintenance.

- For industrial heat, in some cases, hydrogen will be the only viable option for its decarbonization.
- Hydrogen will play an ever more systemic role in the balance of the energy systems as their production costs decrease and the demand increases.
- As the costs drop and the prices of carbon rise, renewable hydrogen and hydrogen with a low carbon content will be competitive vis-à-vis the gray hydrogen that is currently used as a raw material of the industry.

As demonstrated by the study from the Hydrogen Council in the transport sector, hydrogen is already competing with other fossil energies and Fuel Cell Electric Vehicles (FCEV) have been slowly occupying space among the low-emissions models that are available in the market. The sales of this type of vehicles have intensified in the last years and, thanks from the impulse from some policies in favor of hydrogen as a fuel, sales volumes in 2019 were very significant. However, the number of FCEV circulating is still insignificant in relation to the BEV[7] o PHEV[8]: for each fuel-cell electric car there are around 120 PHEV and almost 250 BEV. This reflects various factors such as the later introduction of the FCEV, the lesser availability of models in the commercial market and greater investment requirements per service station, as well as the lack of recharge infrastructure (IEA, 2020).

In 2019, 12.350 FCEV were sold, which raises the world stock to 25.212 units, including passenger cars, buses and trucks. This more than doubles the figures of 2018, when global sales were of 5.800 units and the total stock was 12.952 FCEV (AFC-TCP, 2020).

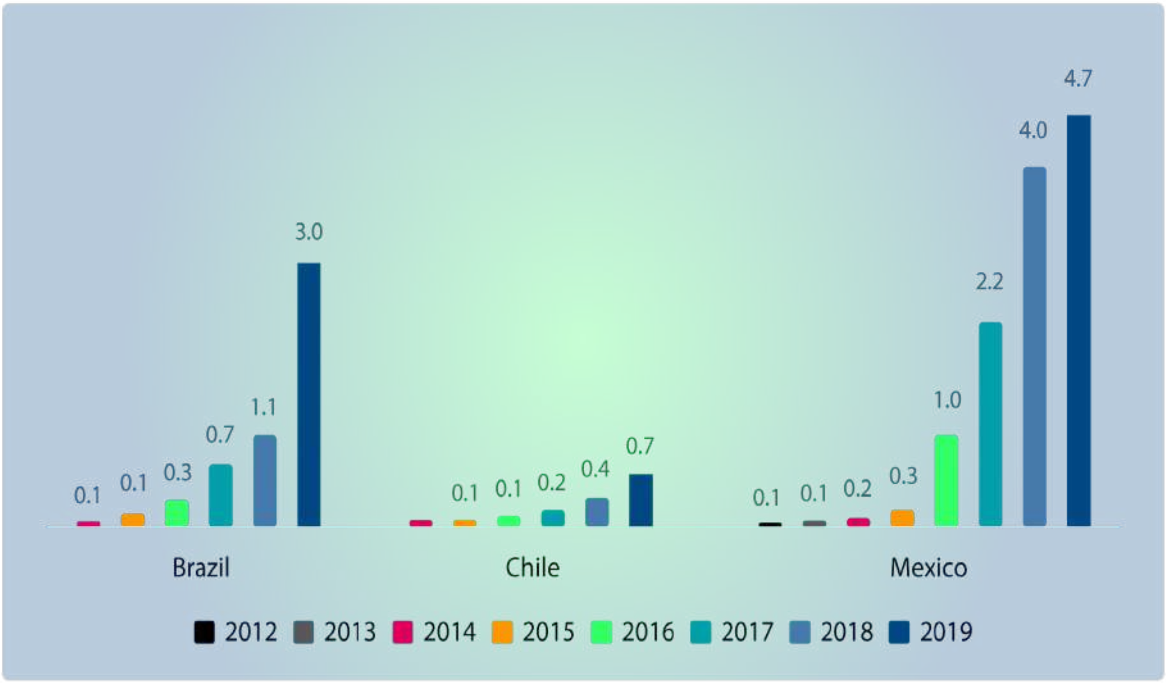
In Latin America, the FCEV have not yet been incorporated into the market of “clean” vehicles. The fleet of

7 BEV: Battery Electric Vehicles

8 PHEV: Plug-in Hybrid Electric Vehicle

electric vehicles only contemplates BEV and PHEV. Brazil, Chile and Mexico, the three countries with the largest fleet of this type of vehicles in the region, as a whole, amount to a cumulated total of a little more than 19 thousand, between the years 2012 and 2019, or el 0,3% of the world's stock, which reaches 7,2 million. In graph 1 we observe the quantity of electric vehicles incorporated annually into the respective vehicle grids of these three countries.

Graph 1. Quantity of electric vehicles incorporated annually into the vehicle grid of Brazil, Chile and Mexico, between 2012 and 2019 (in miles)



Source: IEA, 2020.

The executive director of Porsche, a German sports car producer, according to what was published by the Terram Foundation (2020), stated that "at Porsche, they believe that ecofriendly eFuels have a potential for being an important element in carbon-neutral transport, and that, "for our customers, green fuels are an opportunity for driving sustainably a combustion engine Porsche". He also said that 70% of Porsche cars built are still on the streets and, therefore, "for many years there will be vehicles with conventional combustion engines". It is probable that, just like Porsche, many other auto companies will seek to delve into the production of vehicles running on this type of energy, in order to guarantee the supply until their business model migrates toward more advanced, zero-emission vehicle technologies.

For Volkswagen, according to an article published on the Drive Volkswagen Group Forum website[9], it is very possible that fuel cells or synthetic fuel will acquire greater importance in the medium or long term. But none will be available on an industrial scale by the mid 2020s, and certainly not at reasonable prices. Long-distance driving and quick fuel replenishment make the fuel cell systems viable for long-distance electric transport, but only if the hydrogen is green and produced by electrolysis from solar and wind energy sources. In the article, the company warns of the importance of taking into account the losses of efficiency of the conversion process because, unlike with the battery, the energy cannot be consumed directly. Another factor that slows down the adoption of hydrogen as a motor vehicle fuel is the absence of charge infrastructure. Although 400 stations are being planned in Germany for 2023. About 3,000 will be needed to cover the country. The makers of Asian automobiles currently lead the market of hydrogen propulsion systems.

9 Drive Volkswagen Group Forum. Battery technical. Why doesn't Volkswagen use fuel cells and hydrogen drive systems? https://drive-volkswagen-group.com/en/question/why-doesnt-volkswagen-use-fuel-cells-and-hydrogen-drive-systems/

GREEN HYDROGEN AS AN ENERGY ALTERNATIVE

As a source of energy and fuel, H_2 or green hydrogen offers ways for decarbonizing an ample range of sectors, including transport, chemical products, iron and steel, and other sectors.

It contains more energy per mass unit than natural gas or gasoline, which makes it attractive as a fuel for transport. However, since it is the lightest element, it has a lower energy density per unit of volume.

Did you know?

According to the International Energy Agency (IEA), "black", "gray" or "brown" hydrogen refers to hydrogen produced from coal, natural gas and lignite, respectively.

"Blue" hydrogen is produced from fossil fuels with mitigated and reduced CO2 emissions. On the other hand, **"green"** hydrogen is made from electricity generated with clean or renewable sources.

Although a few countries constituted the largest part of the world's demand, 85 countries require hydrogen.

Hydrogen is already competing with other fossil energies and Fuel Cell Electric Vehicles have been occupying space in the market.

Green hydrogen is still 2-3 times more expensive than blue hydrogen and, in order for it to gain space, its costs must undergo important reductions, which must also include its infrastructure.

In Latin America, the hydrogen produced is used mainly in the industrial sector or for refinery processes. Another application is the manufacture of ammonia, a component of agricultural fertilizers.

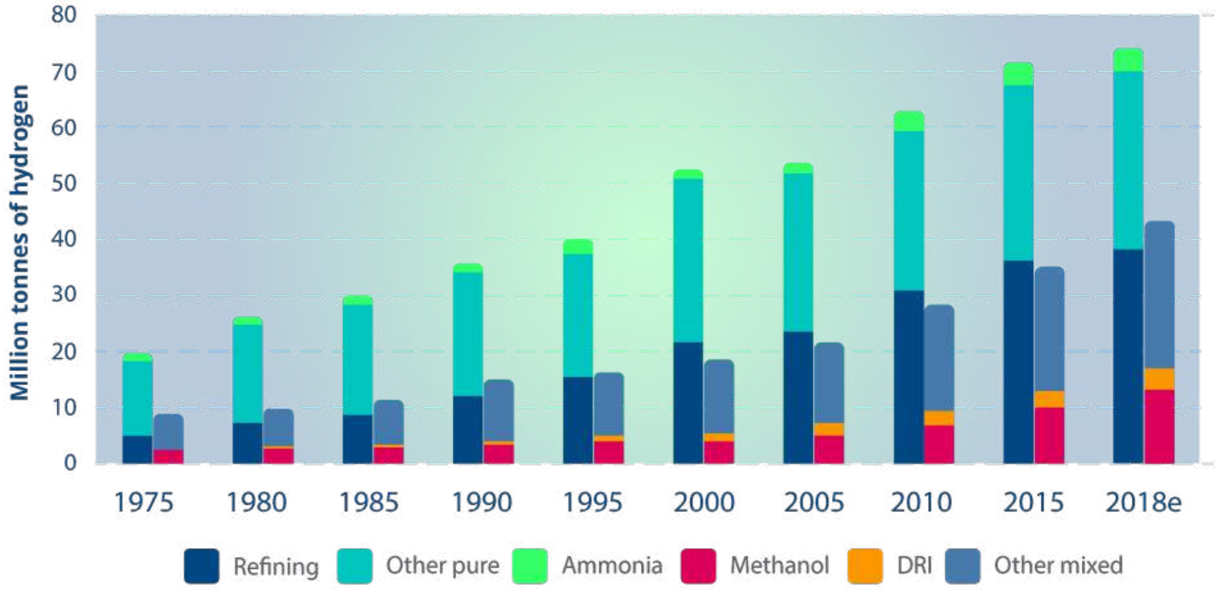
According to the Hydrogen Council, in 2030 hydrogen could satisfy 15% of the world's energy needs in a competitive manner and the massification of its use is the greatest drive for reducing costs, which are identified as the main barrier for its massification.

2.3 Hydrogen demand and offer

According to the Hydrogen Council, 2020, in 2030 hydrogen could satisfy 15% of the world's energy needs in a competitive manner and the massification of its use is the greatest drive for reducing costs, which are identified as the main barrier for its massification. However, achieving an economy truly based on hydrogen, where it is used instead of gas, for heating and balancing the electric grid, for example, according to S&P Global Ratings (2020), seems to be out of reach, at least before 2030, unless policies are defined for zero carbon emissions and renewable energies that comprise at least 70%-80% of these sources in the energy combination.

The supply to industrial users has been gradually transforming into an important business worldwide. The demand, which has tripled since 1975, keeps increasing. In its pure form, it is close to 70 million tons per year (MtH_2 / year) (Figure 1). This hydrogen, given that it is obtained almost in its entirety from fossil fuels (76% natural gas and 23% coal), is responsible for the emission of around 830 million tons of carbon dioxide per year ($MtCO_2$ / year), equivalent to the emissions of Indonesia and the United Kingdom together. In terms of energy, the total annual demand for hydrogen worldwide is around 330 million tons of ions of oil equivalent (Mtoe), greater than the supply of primary energy of Germany (IEA, 2019).

Figure 1. Demand for hydrogen (1975-2018)



Source: IEA, 2019

According to Wood and Mackenzie (2020):

- During the last decade[10], the world's demand for hydrogen grew by 28%, reaching a maximum in 2020 with 111,7 million metric tons or 320 Mtoe[11]. Although this seems much, it is not significant if compared with other new energy technologies.
- The 10 main countries demand 70% of the world's production of hydrogen. China and the United States represent 21% and 19%, respectively. The refined and ammonia dominate two thirds of all the uses for the demand. In transport, the participation is much reduced.
- Although a few countries and sectors constituted the largest part of the world's demand in 2020, 85 countries require hydrogen. However, individually, 61 countries represent less than 1% of the world's demand. This is evidence of the potential for delving into markets where hydrogen is still not much used.
- Currently, hydrogen is produced almost exclusively by hydrocarbons. Gray, brown and black hydrogens combined constitute 99,6% of world production. So, although there is much noise regarding green hydrogen, there is little use on record.

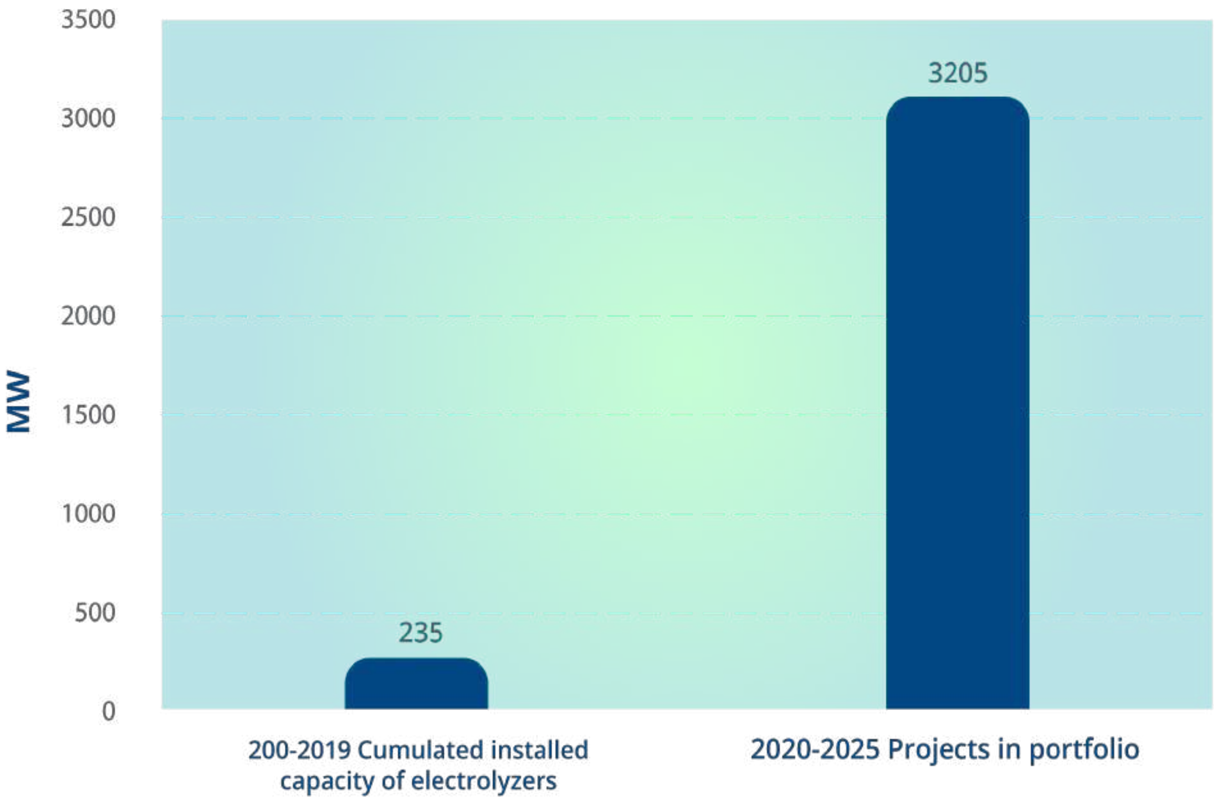
10 At https://www.woodmac.com/nslp/hydrogen-guide/

11 Mtoe = Millions of tons of oil equivalent

The study by Wood Mackenzie indicates, moreover, that since 2000 up to late 2019, 252 megawatts (MW) of green hydrogen would have been produced throughout the world and that between the years 2020 and 2025, the installed capacity of electrolyzers dedicated to its production will amount to 3.205 MW, which will mean a twelve-fold increase in comparison to the previous period (graph 2). The study posits that this will be due, in part, to the fact that it is a nascent market. But the aggressive objectives in East Asia and the greater interest from the main international player will drive the deployment in the short term (Roca, 2019).

It is estimated that the green quality that hydrogen could have, if its production is massified from hydrolysis with clean energies, will allow to support the decarbonization of critical sectors such as the steel and cement industries, whose possibilities of emissions reduction through cleaner energy sources, in the current scenarios, is very limited. However, in 2020, its use throughout the world only represented 0,1% of the hydrogen produced (Wood Mackenzie, 2020).

Graph 2. Installed capacity of electrolyzers for producing green hydrogen and future projection (quantity of electrolyzers and MW)



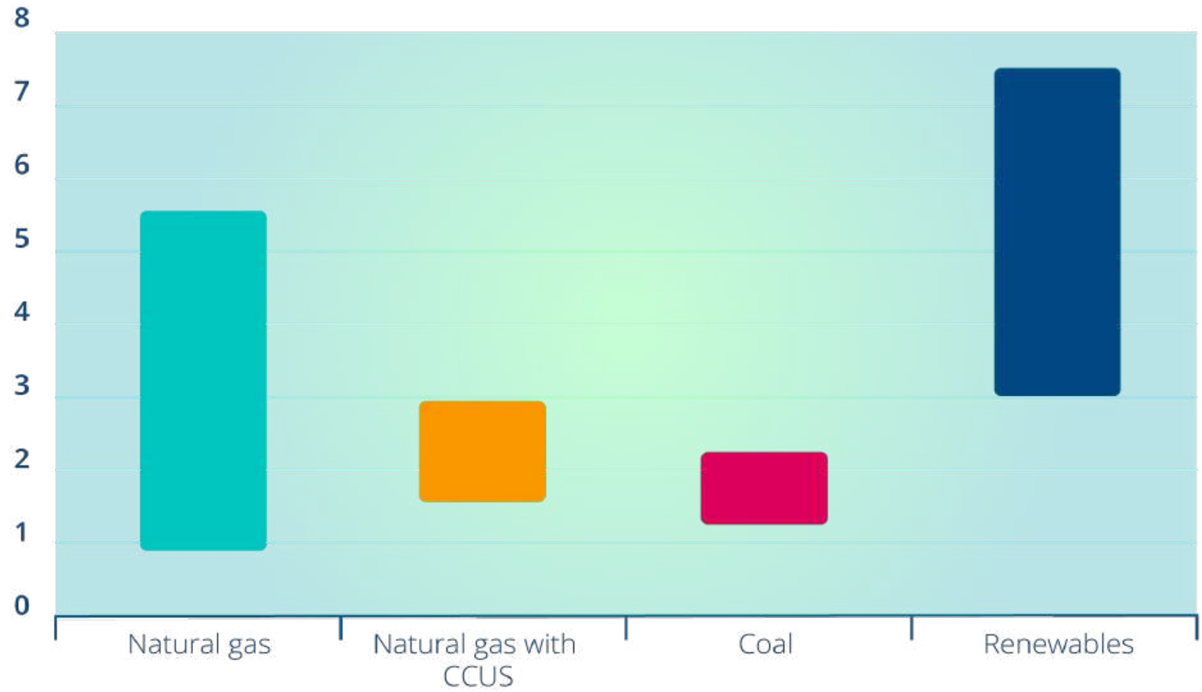
Source: Wood Mackenzie, 2020.

2.3.1 The cost

The cost is particularly important in the case of green hydrogen, which, though it may continue to decrease due to the constant price drops of the energies generated from solar and wind, is still not competitive compared to fossil energies in general, and with natural gas (NG) in particular, which, in many countries is also considered to be a “transition” resource within their respective climate strategies. Green hydrogen is still 2-3 times more expensive than blue hydrogen and, in order for it to gain space, its costs must undergo important reductions, which must also include its infrastructure (electrolyzers, storage, transport and distribution) (IRENA, 2020), in order to unseat natural gas (NG), the main energy source for the production of this gas and, at the same time, one of the most widely used energy sources for the production of electricity in various countries. Figure 2, accounts for the compared value of producing black, gray, blue and green H_2, from different energy sources.

In 2018, the contribution from natural gas to the generation of electricity throughout the world reached 23%. In the European Union, the proportion was of 19%, the same as in South America in 2019. In this region, depending on the country, the use of NG is intensive and will probably continue to be in the immediate future. The largest users, according to data from the International Energy Agency[12], in 2019, are Argentina, where its use reached 65%, followed by Bolivia, with 62%, 38% in Peru and 25% in Venezuela. While in Brazil, proportion was below 10% and in Uruguay this fuel is practically not used to generate electricity.

Figure 2. Cost of production of H_2 from different energy sources (data from 2018) (dollars/kg)



Source: IEA, 2020a.

Its price, undoubtedly, is in favor of NG. According to a study conducted by OLADE, with the support from IDB, which calculated the end-price of the energy most commonly used in some countries of La tin America and the Caribbean, where NG is part of its energy matrix, it is significantly cheaper than electricity (see chart 1). The study defines the price as the average unit price effectively paid for a type of consumer during the established period. That is to say, the end-prices of the energy correspond to the relationship between the total amount of money spent on the purchase of electricity or fuels, and the total volume of sales of this energy throughout the trimester or year (OLADE, 2020).

12 See https://www.iea.org/regions/central-south-america

Table 1. Price of some fuels in Argentina, Bolivia and Chile.

Country	Energy	VAT %	Special taxes	Price
Argentina	Residential electricity	21	no	102,5 dollars/MWh
	Industrial electricity	no	no	79,51 dollars/MWh
	Residential NG	21	yes	7,28 dollars/Mbtu
	Transport NG	21	yes	11,27 dollars/Mbtu
	NG generation	no	no	2,73 dollars/Mbtu
	LPG (residential)	21	yes	0,243 dollars/kg
	Gasoline	no	no	1,12 dollars/kg
	Diesel	21	yes	0,90 dollar/l
Bolivia	Residential electricity	13	no	12,01 dollars/ MWh
	Industrial electricity	13	no	9,71 dollars/ MWh
	Residential NG	14,94	no	5,33 dollars/Mbtu
	Transport NG	14,94	no	6,5 dollars/Mbtu
	NG generation	14,94	no	1,35 dollars/Mbtu
	LPG (residential)	14,94	no	0,32 dollars/Mbtu
	Gasoline	14,94	yes	0,54-0,69 dollars/l
	Diesel	14,94	yes	0,53 dollars/l
	Diesel generation	14,94	no	0,16 dollars/l
Chile	Residential electricity	19	no	129,56 dollars/ MWh
	Industrial electricity	19	no	88,84 dollars/ MWh
	Residential NG	19	no	87,83 dollars/Mbtu
	LPG (residential)	19	no	0,95 dollars/kg
	Gasoline	19	yes	1,28-1,36 dollars/l
	Diesel	19	yes	1,0 dollars/l

Source: OLADE, 2020.

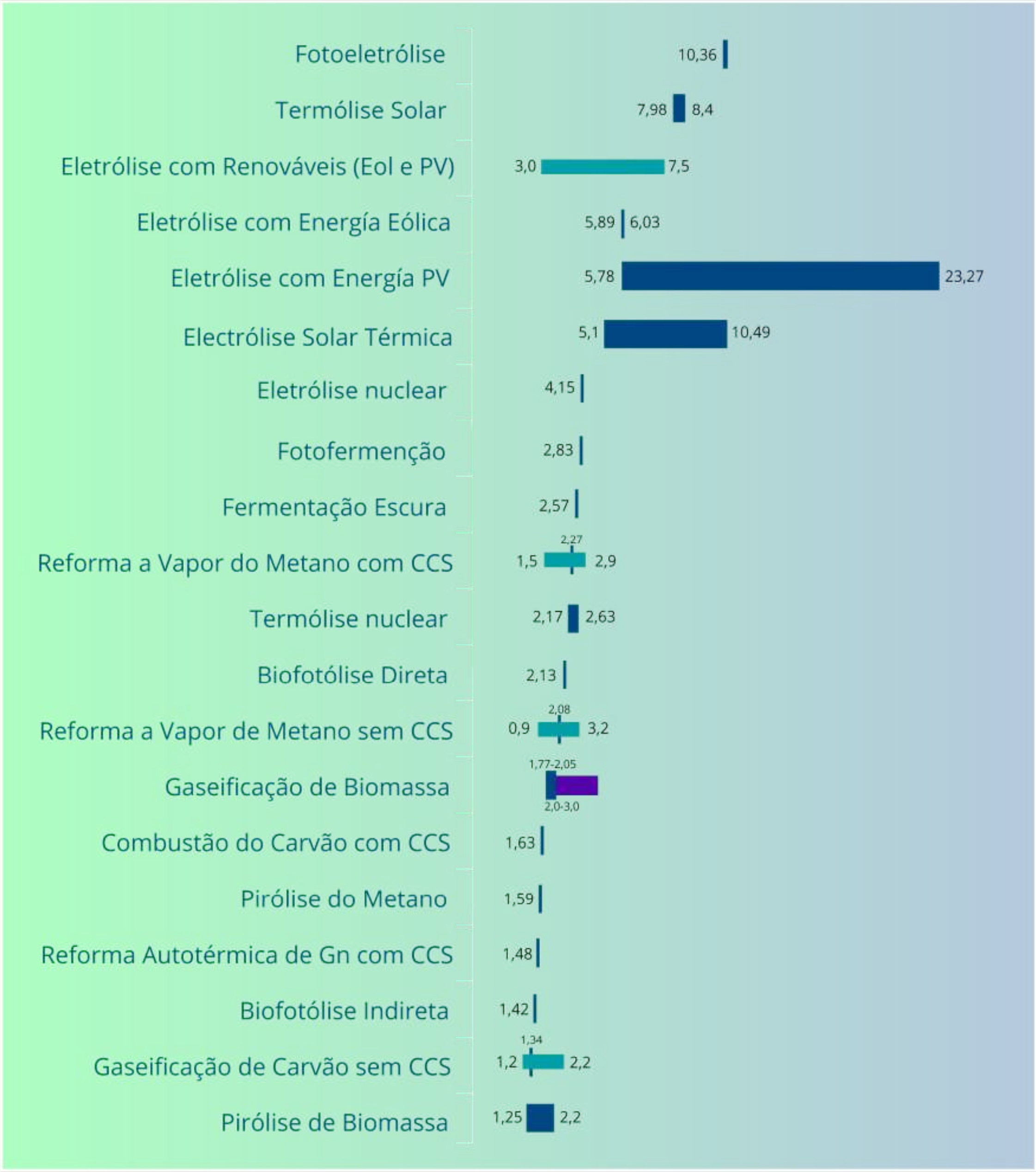
According to data from EPE (2021), based on the data published by IEA (2020a), fossil sources as a technological basis for H_2 production, has a lower costs than the electrolysis with the generation of renewable electricity. Specifically, the lower production costs are those for the steam methane reforming method (natural gas) and the gassing of coal, technological paths based on fossil energy sources. The electrolysis of water, using renewable sources (wind and solar) is, in general, the most expensive among those already available in the market. Figure 3 accounts for the production cost ranges of the different technologies currently available, considering the gassing of biomass, which is not yet a mature technology.

[...] the production of green hydrogen will be able to compete with the hydrogen produced from fossil fuels in 2030 in Australia, Germany and Japan, but only if the prices of renewable energy reach, at least, 30 dollars per megawatt hour (MWh).

An electrolyzer plant based on water, in 2017 and 2018, required an investment of around 20 to 30 million dollars annually, and the associated investments: storage tanks, fuel replenishment infrastructure, pipelines and other equipment, increase even more the total investment of the project. Therefore, the bet is on massification.

According to a study by Wood Mackenzie, cited by Roca (2019a), the production of green hydrogen will be able to compete with the hydrogen produced from fossil fuels in 2030 in Australia, Germany and Japan, but only if the prices of renewable energy reach, at least, 30 dollars per megawatt hour (MWh). Today, the prices of the wind and solar energy purchase agreements vary between 53-153 dollars / MWh in those markets. According to IRENA (2020), an energy cost of 20 dollars / MWh, translates into an end-cost of hydrogen of 31 dollars / MWh, almost 1,5 dollars per kg of $H_{2,}$ so the 30 dollars assumed by Wood Mackenzie are still very high and insufficient to drive the competitiveness of green H_2.

Figure 3. Cost range for H2 production by technology and energy source



Source: EPE,2021.

But, depending on the location, these costs are already equatable to those for producing blue hydrogen. This happens, for example, in Chilean Patagonia, in the Magallanes Region, where wind energy has a plant capacity of almost 50%, with an electricity cost of 25-30 dollars / MWh, which is expected to decrease to 10-20 dollars / MWh until the middle of the century. The current cost will already be sufficient to achieve a green hydrogen production cost of approximately 2,5 dollars/ kg, a value close to the range for blue hydrogen. But the country's strategy in terms of green hydrogen contemplates that by 2030, they will achieve 25 GW by electrolysis, with a production cost below 1,5 dollars / MWh, and by 2050, 1,2 dollars / MWh, an amount far from being the lowest at the global level (IRENA, 2020 and Ministry of Energy of Chile, 2020). This implies advancing the reduction projected for the middle of the century, by 2030. To date, a green hydrogen pilot plant is already accomplishing the permit formalities with the authority from that southern region of Chile for its construction. These values could be replicated in Argentina.

As has been mentioned, hydrogen costs vary widely and are strongly influenced by those of natural gas, nowadays its main source of energy and of renewable energies, which has a direct impact on its end-price. According to the evaluations of the price of hydrogen by Platts[13], the prices of gray hydrogen in October 2020 averaged around 1,25 dollars / kg on the Gulf Coast against 2 dollars / kg in California; using the spot prices of energy as input, the price of hydrogen based on proton exchange membrane (PEM) electrolysis would be, respectively, 2,8 dollars / kg and more than 4 dollars / kg. In the Netherlands, the comparable prices for gray hydrogen were around 1,7 dollars / kg (around 0,2 dollars / kg higher for blue hydrogen, which includes CAC). The prices of hydrogen produced by PEM electrolysis are equivalent to 4,3 dollars / kg, using the current spot prices of energy. In Japan, the prices of gray hydrogen averaged 2,7 dollars / kg, while the price of hydrogen by PEM electrolysis averaged 5,3 dollars / kg based on the spot prices of energy (S&P Global Ratings, 2020).

13 Platts's daily price assessments include 10 series of regional prices from the USA, a series from Canada and prices from the Netherlands and Japan. The daily price evaluations show the cost of producing hydrogen through the methods of steam methane reforming (SMR), including in some regions the capture and storage of carbon (CAC) and the production prices by proton exchange membrane (PEM) electrolysis and alkaline electrolysis, at each of the key production centers. The prices calculated reflect both the production cost of the basic products and the capital expense associated with the construction of a hydrogen installation. See: https://www.spglobal.com/platts/en/our-methodology/price-assessments/natural-gas/hydrogen-price-assessments

2.3.2 The risks

Aside from the cost and the environmental impacts, especially due to hydrogen production and use, probably the main barriers that currently affect the demand for hydrogen, another hindrance to the massification of its production and utilization in activities such as transport, for example, are some risks that are still latent and that must be solved in order to increase the safety of its use and to improve the perception by the users regarding this energy.

The use of hydrogen entails safety risks, high initial infrastructure costs and risks associated with some industrial dynamics of supply and distribution of fossil fuels, especially when combined with CAC, but it is unclear how the citizens will react to these aspects. Or how they will ponder them when they compare them to the convenience and the environmental benefits of some of their applications, as well as the potential importance of hydrogen for sustainability in the long term (Backer and MacKenzie, 2020). Another risk that several scientists urge to be taken into account is related to the impact of hydrogen on the atmosphere and, therefore, on the climate dynamics of the planet, although it is a secondary greenhouse effect gas. This has been, so far, scarcely described due to the still low knowledge of its cycle.

Moreover, the participants in the process of amplification of hydrogen use must take into account other risks, such as financial, institutional and legal, especially in the current stage, where the “hydrogen economy” is just being built and needs guarantees to solidify. These, though perfectly mitigable, depend on the maturity of the thematic of each country and of its respective strategies and expectations, should they exist.

Photo by Tommy Kwak, source: www.unsplash.com

Risks to health and safety

Just as other energy sources, hydrogen presents some risks for health and safety when used on a large scale. Therefore, it is estimated that the considerations of safety and the incidents, in order not to slow down or prevent the deployment of this new energy technology, must be well known and adequately and timely regulated, managed and communicated.

As a small-molecule light gas, hydrogen requires special equipment and procedures for its handling. Although it is not a toxic gas, its high flame speed and the wide range and low range of ignition make it highly flammable. This is mitigated in part by its high floatability and diffusivity, which causes it to dissipate rapidly. It has a flame that is not visible with the naked eye, since it is colorless, as well as odorless, which makes it difficult to detect fires and leaks manually (IEA, 2020).

Hydrogen is considered to be as safe as gasoline or any other common-use fuel, but one must understand the differences among these fuels and how to work safely with this gas. A factor favoring its use is the many decades of experience in the industrial sector and in large dedicated distribution pipelines. The protocols for safe handling at these sites already exist, and also for the infrastructure of hydrogen replenishment at specific sites.

However, it is still a complex and unknown issue in comparison to other energy carriers. Its generalized use in the energy system would bring new challenges. They would need a greater development and any pubic preoccupation should be minimized.

The considerations of health and safety of the majority of fuels and hydrogen-based raw materials are familiar to the energy sector. The exceptions are ammonia and other liquid organic hydrogen carriers (LOHC), whose potential use in the energy system have only recently started to be taken into account. In general, ammonia poses more health and safety considerations than hydrogen, and its use would probably have to be restricted to specific and trained operators. It is highly toxic, flammable, corrosive, and it escapes in its gaseous form. However, unlike hydrogen, it has a pungent smell, which facilitates leak detection. It is also a precursor of air contamination.

Like with hydrogen, there is a long experience in the industrial use of ammonia. It has been used as refrigerant since the beginning of the XIXth century and also in the production of fertilizers on a large scale for more than a century. Ammonia is routinely stored and transported, including on ocean tank vessels, and it is sometimes injected directly into the ground in agriculture.

For H_2 Tools[14], the physical risks of hydrogen -leak, flames and explosion-, can be easily confronted with actions that do not differ much from those that are already carried out when handling other types of fuels.

14 The Hydrogen Tools Portal was developed by The Pacific Northwest National Laboratory, with the support from the U.S. Department of Energy's Office of Energy Efficiency and Renewable Energy (EERE)

Financial risks

Considering the projections for growth of the hydrogen markets in the medium and long term, the first companies that will invest may tap this growth, become technological leaders and shape the business. For some, such as those with a wide portfolio of natural gas, investing in hydrogen energy also has the additional advantage of a long-term future for its assets.

However, there are still multiple barriers for the generalized development of decarbonized hydrogen, and each investment will face challenges regarding the policies and regulations, aside from the economic and financial ones. The first ones to move in this field will have to have government support in order to reduce the investment risks regarding its cost, one of the main barriers for its massification.

The speed of deployment of hydrogen will vary between sectors and countries, and these variations are due in part to the different levels of maturity or adoption of the technology necessary for the development of its green variant, either at the global level or in specific regions. The details of the strategy defined for the different governments will affect the opportunities that can be effectively leveraged, so it is crucial to dominate them, as well as the legislation and the financial sources.

Some of the obstacles identified by the participants in this survey conducted by Backer and MacKenzie (2020) in order to advance more rapidly and with a lower risk in the deployment of this energy, are still present today:

- There are no systems of "guarantee of origin" that allow to distinguish among the different types of hydrogen according to the emissions of greenhouse effect gasses associated to its production. Therefore, there is no clarity as to how to leverage the advantages of producing it in a clean fashion, especially considering its production costs, which are still high;
- The scarcely clear legal status of the plants or the "power-to-hydrogen" storage system can prevent said plants from be rewarded according to the service effectively rendered to the energy system;
- Rules for industrial emissions or safety that are scarcely clear, incomplete, obsolete or counterproductive;

- Financing norms that are incoherent or unfavorable;
- Obsolete rules in the gas and electricity markets;
- Government discrimination of specific technologies and processes based on prejudices.

In some of the countries committed to the development of hydrogen, many of these normative barriers are already in the process of being dismantled and reformed, and it is expected that the European Union will give a great boost in all of these areas in the next years, which will be certainly followed by the countries that seek to penetrate that market. Many governments are already providing their support to the growth of hydrogen through innovation funds, mandatory objectives and public-private associations

Nonetheless, in order to guarantee the profitability of their investment -this applies especially to the pioneers- the following must be evaluated: (i) the effect of the existing normative barriers over any new investment or project, (ii) the probability that said barriers may disappear for a concrete market and on a given deadline, (iii) the availability of public aid for eliminating the investment risks whenever necessary (Backer and MacKenzie, 2020).

Aside from a careful assessment and monitoring of the government strategies and the existing policies, the pioneers must have the direct support from the government in order to reduce the investment risks during the first years of this emerging market. To that effect, it is important to act in the areas and the markets where government support is abundant. In order to take full advantage of this support, the companies must know (i) what companies offer the larger amount and the best approach for financing or supporting the investment and (ii) what types of projects are considered a priority and are supported by the respective governments. (Backer and MacKenzie, 2020)

The companies that contemplate a specific investment in their own region and field of experience must conduct an exhaustive analysis of the financing opportunities and of the available funds. For each possible value chain of hydrogen, the investments and policies must be synchronized on the scale and time for its production and delivery to the end-users, and have to create trust across the board, in order that the investments may be coordinated without delay, which may require new contractual relations. In some cases, the governments and companies will have to think and seek novel ways that involve other sectors in order to make the most of the flexibility of hydrogen.

Infrastructures such as pipelines and supply networks are especially important for a new energy vector such as hydrogen, but these, in turn, require high amounts of resources in order to be implemented. In many countries, where the ability of the governments to commit to these investments is limited, the public-private investment models came back to the fore. Two examples in the region are Chile and Uruguay, where this business model has been used successfully in the last decades. In some cases, these investments may require, additionally, cross-border cooperation, which requires an international collaboration at a level that has yet to be seen in the case of hydrogen (IEA, 2019).

But, probably the greatest risk that the pioneers must confront in relation to green H_2 is related to the fact that, although the ambition of climate change is still the most important driver for its generalized use, the speed with which the governments will drive the transition towards low-carbon energy sources is still a great uncertainty (IEA, 2019). Though low-carbon hydrogen may be attractive in the short term in certain applications, its strong point is its capacity to help to reduce emissions and to provide support to the stability of the electric matrix, thanks to its ability to manage very high levels of variable renewable electricity. Inasmuch as there are clear commitments, and ideally binding, with sustainable and resilient energy systems in the long term, committing financially to the technologies and infrastructures of hydrogen is much less attractive and riskier.

The majority of the applications of hydrogen with low carbon emissions are not competitive from the standpoint of costs without the direct support from the governments. What is not clear either is the relative costs of producing hydrogen from the different sources in different regions and how they will compete in the future. This hinders the comparison of future prices of hydrogen with those of other alternatives, such as the solid-state batteries, hydroelectric energy for pumping, electric vehicles, biofuels and the electrification of high-temperature heat, many of which have an advantage and which could also benefit from it. In the case of fuel cells, the speed of cost reduction is a key factor. However, the experts still have not reached an agreement as to the relationship among scale of the demand, cost and yield improvements.

The technological uncertainty is also evident in the debates over the forms in which hydrogen could be transported through long distances and the formats in which it could be delivered to the end-users.

Normative and institutional risks

An institutionality that provides security and a regulation according to the momentum created by hydrogen appears as something that is not only fundamental, but also urgent. If, on the one hand, this is a way of mitigating the financial risks that imply, above all, the implementation of innovations, on the other hand, it increases the possibilities of investments and the opening of markets, especially at the international level.

In turn, the economic and political stability of a country allows to reduce the investment risks, which helps to decrease the costs, for example, of installation and operation, thus lowering the value of capital, with long-term credits and lower interest rates. This opens the appetite for investing in these economies.

Throughout the world, the current state of the legislation and existing standards still limits the acceptance of hydrogen as energy. Some regulations are not clear or do not consider the new uses that it could have and do not allow the exploitation of all the benefits that it can bring. Those that already address technical questions, such as how and where pressurized or liquefied hydrogen can be used, who can handle it, where hydrogen vehicles may go, what are the fiscal regimes for the conversion among energy vectors, whether CO_2 may be stored and how, how much hydrogen can be present in natural gas pipelines, must all be updated in order that hydrogen may have the opportunity to develop its potential (IEA, 2019).

In South America, the regulation of hydrogen as an energy source is nonexistent or insufficient, generic and is out of date, since it is regulated as a hazardous substance, without recognizing all of its value chain or without considering the specificities for its potential uses or possibilities of application in the industry[15] and in other fields. As it is not considered to be a fuel but, rather, only a chemical element, its use, production, storage and sale are currently limited.

The only law that regulates hydrogen as a fuel in the region is from Argentina (Law 26.123 of August 2006). But this law, in Art. 2, only states in general terms that it "promotes research, development, production and use of hydrogen as a fuel and an energy vector, generated through the use of primary energy and

15 Regulatory challenges for the development of green hydrogen in South America. Mining Law, Energy and Natural Resources. Published on October 19, 2020 at https://www.ppulegal.com/insights/prensa/desafios-regulatorios-desarrollo-hidrogeno-verde/

regulates the leverage of its utilization within the energy matrix", and makes no reference to green hydrogen. Indeed, when it was promulgated, the colors of hydrogen were not being distinguished yet. In practice, this law is inapplicable because its rules of execution have not been crafted yet and if this does not materialize by the end of 2021, the law will expire. Hence, there is a great interest in updating it or replacing it, which probably explains the lack of interest in regulating it, as there would be an awareness of its insufficiency for stimulating production and development of green hydrogen in the domestic and international market.

Green hydrogen must still be regulated as an energy and, although it is considered to be a clean fuel, the new normatives must not ignore the environmental risks associated to its production, uses, storage and transport [...]

In Chile, since February 2021, this gas is considered to be among the energies within the purview of the Ministry of Energy. This is the case since the modification of Art 3 of Decree Law 2.224 of 1978, which created the Ministry of Energy[16]. But the normativity still must be adapted, or created, in order that the country may comply with the National Strategy related to this gas, published at the end of 2020.

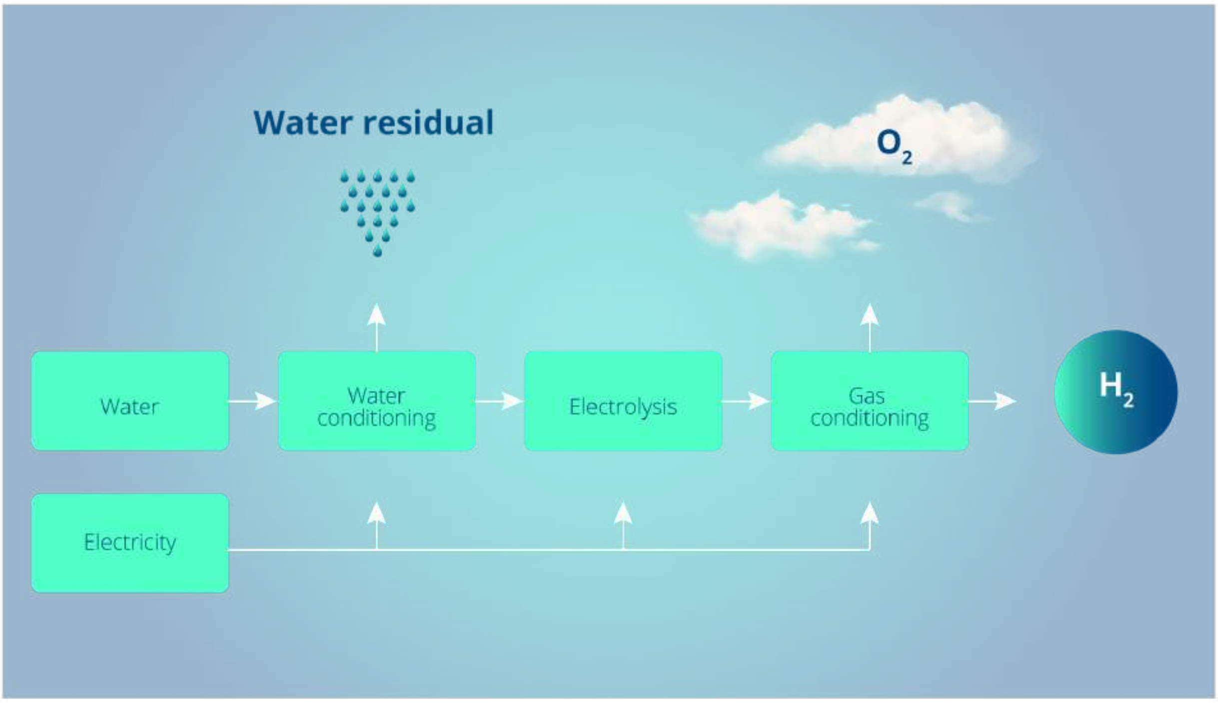
Green hydrogen must still be regulated as an energy and, although it is considered to be a clean fuel, the new normatives must not ignore the environmental risks associated to its production, uses, storage and transport, so its regulatory framework will demand an ample and profound technical knowledge, aside from legal and fiscal, which, on the whole, may promote and generate an environment propitious for its production, use and commercialization. It is probable that not many countries in the region have this installed capacity in the legislative bodies or are concentrating their attention on this field in the short term.

16 At https://www.cne.cl/archivos_bajar/DL_2224.pdf and https://www.bcn.cl/leychile/navegar?idNorma=6857&idParte=8628649&idVersion=

Environmental risks

In order for hydrogen to be green, it must be produced through electrolysis of water and used as an energy basis, the electricity generated from clean sources. As all production processes, this one is not exempt either from environmental impacts that require attention and normative advances to prevent and minimize them. In general terms, the stage of operations of the green hydrogen plants is the one that poses the greatest proportion of impacts and risks for the environment. But, unlike other production processes, these plants only release Oxygen and do not generate NO_x, CO_2, particles or Total Organic Carbon, so no preventive measures would be necessary to that effect. Diagram 2 illustrates in a simplified way the production process of green hydrogen.

Diagram 2. Supplies, products and waste from the production process of green hydrogen



Source: Inodú, 2020.

These are the environmental risks to be taken into account:

- Water discharges and consumption. The hydrolysis plants generate a reject water, which is expected to increase considerably its conductivity, which is why the preventive measures must be aimed at controlling this factor. A consumption of 50% is expected, that is to say, half of the water input is returned. An average of between 10 to 12 liters of water is required for producing one kilo of hydrogen. In this regard, in situations of hydric scarcity, the technical feasibility analyses must be very careful, as well as the solutions for the disposal of the waters used in the process.

- Generation of waste. The main waste generated pertains to the treatment of waters from the electrolysis equipment: mainly inverse osmosis membranes, cartridges for the pretreatment of water, ionic interchange resins, etc.

- Disruptions on the fauna and flora. Generally, only those inherent to the installation of renewable energy (wind or solar) associated to the plant are considered. But, both ecosystems can be affected also by the reservoirs of clean and waste water, if such were the case, or hydric scarcity.

- Production of noise and vibrations. The electrolysis process is silent, since it is an electrochemical reaction, but the compressors produce noises and vibrations.

Regarding the use of hydrogen as a fuel, different studies suggest that this could worsen global warming due to possible uncontrolled emissions that could affect the chemical reactions of the atmosphere, a problem that is scarcely addressed by the literature and even more scarcely by the decision-makers. Indeed, the most abundant bibliography on this topic is from the decade of the 2000s, and there aren't more recent sources, at least publicly. Moreover, in this regard, there are still important uncertainties that science still has not been able to solve.

One exception is a document commissioned by the Department for Business, Energy and Industrial Strategy of the United Kingdom, to scientists, published in 2018. Its objective was to detect, through a bibliographical review, the potential impacts of the increase of hydrogen emissions into the atmosphere due to the leaks in a system based on this gas for heating. The review concluded that there were two global atmospheric disadvantages of a future hydrogen economy: its increase in the atmosphere will produce the depletion of atmospheric ozone through the increase of moisture of the atmosphere, and the contribution to climate change through the increase of growth rates of methane and tropospheric ozone (BEIS, 2018).

According to a study by Tromp et al (2003), the generalized use of hydrogen fuel cells could have environmental impacts hitherto unknown due to the unintentional emissions of molecular hydrogen, including the increase of water vapor in the stratosphere. This would cause its cooling, an increase in the chemistry that destroys the ozone, the increase of noctilucent clouds[17] (apparently, due to the increase in methane) and changes in the chemistry of the troposphere and in the atmosphere-biosphere interactions. They estimated that, if hydrogen were to replace all fossil fuels, 60 to 120 billion grams of hydrogen would be released annually in the atmosphere, assuming a loss for leaks of 10 to 20%. This would be four to eight times more than the hydrogen currently emitted by human activities.

According to Derwent et al (2006), if a hydrogen global economy were to replace the current energy system based on fossil fuels and its leak were of 1%, it would produce a climate impact of 0,6%. If the leak rate were of 10%, the climate impact would be of 6% of the current system. According to what is known so far, hydrogen can increase global warming by 20-30% with respect to methane if it leaks into the atmosphere, so it is indispensable to reduce to a minimum hydrogen leaks in the synthesis, storage and use of this gas if we want to achieve all the climate benefits in comparison with the energy systems based on fossil fuels.

17 These are ice formations that appear in the highest part of the atmosphere, with altitudes around 85 km. They trace the conditions that prevail at that altitude and constitute the only source of information about these layers of the atmosphere, because that zone is too elevated to be reached by balloons, but is too low for artificial satellites to place themselves there in stable orbits.

03 The production environment and perspectives in some countries of Latin America

Although in the region it could be said that only two countries -Chile and Costa Rica- have advanced consistently and rapidly in defining hydrogen formally as a clean energy alternative that will help them meet their commitments of emissions and the carbon-neutrality of their economies, another group of countries is starting to materialize initiatives in this same direction. Even with different degrees of advancement, this group of countries has developed activities both in normative and in strategic terms. They are developing studies and implementing pilots and other tests. They have established public-private and international alliances, and they have founded different specialized associations on the matter. Argentina opened more than 10 years ago the first green hydrogen plant in the world and, at the same time, promulgated the first law that regulates this energy in the region. Mexico and Brazil, countries with a great potential and, above all, great internal markets and possibilities of access to international markets, consider the use and/or utilization of H_2 as an energy in their respective energy policies. But, in the case of Mexico, this is only in the mid-term. In Brazil, however, the National Energy Policy 2050 considers the possibility of mixing hydrogen in pipeline networks of natural gas as a way to promote its use. The issue was also proposed in the National Hydrogen Plan of Argentina. However, it is not clear whether it has been implemented. Hence, the novelty of what the Brazilian Policy considers.

In a third group of countries, though not as advanced as the aforementioned, green hydrogen is also starting to become a part of its public agendas and are developing different activities in that sense. That is to say:

Uruguay, according to the Ministry of Industry, Energy and Mining[18], has many attributes for being a producer of green hydrogen to be exported, consumed locally directly and in industries related to the production of raw

18 Green hydrogen, a key link for completing the energy transition. Latest update: 2021/04/05, published at https://www.gub.uy/ministerio-industria-energia-mineria/comunicacion/noticias/hidrogeno-verde-eslabon-clave-para-completar-transicion-energetica

materials and green chemistry, which, themselves, may be consumed locally or exported. Moreover, green H_2 constitutes one of the pillars of the second stage of energy transition that is starting to materialize in the country. In this context, they are currently working within the framework of a technical cooperation with the Inter-American Development Bank (IDB) in order to craft their development strategy of green hydrogen. The country, moreover, is going to start developing a first pilot of green H_2, from the articulation of public and private efforts. The pilot could be in heavy transport or any other project related to green hydrogen (production of green fertilizers, production of green ammonia as fuel for ships or other projects related to the production of green hydrogen). Uruguay, moreover, allocated non-reimbursable resources for 10 million dollars from the Joint Fund of the United Nations for the Sustainable Development Objectives (SDO). The proposal presented by the Ministry of Industry, Energy and Mining (MIEM) was one out of four selected among 155 initiatives from more than 100 countries. The project consists in performing actions that may allow the country to start its second phase of energy transition. With 98% of the electric matrix coming from renewable sources, with this fund, the country will seek to achieve the transition of the transport and industry sectors to green energy. The development of hydrogen is specifically included in this project.

The potential for renewable energies of Colombia[19] is of more than 50 GW, which creates a great production capacity of hydrogen for internal consumption and export. Based on this potential, the country could produce 5.500 tons of green hydrogen per day, and, assuming a price of 4 dollars / kg, it could obtain income for more than 8.000 million dollars per year[20]. In the course of the year 2021, Colombia has programed the presentation of the roadmap structured jointly by the Ministry of Mining and Energy with the IDB for the production and use of green hydrogen, considering the country's institutional, legal, commercial and financial variables[21].

Peru is also heading in the same direction. The country recently founded the Peruvian Hydrogen Association (H2 Perú) as "a collaborative venue that drives the decarbonization of the economy through the use of green hydrogen, for a resilient and sustainable growth in Peru". The Association seeks to promote the development of a new industry with this energy resource, where the cooperation with the countries of the region is a relevant aspect (See: https://h2.pe/).

19 Green hydrogen is a bet for guaranteeing energy wellbeing. Rodrigo Osorio, head of the State Energy Agency of Puebla, Wednesday, August 05, 2020. At https://expansion.mx/opinion/2020/08/04/el-hidrogeno-verde-es-una-apuesta-para-garantizar-el-bienestar-energetico

20 Green hydrogen drives industries such as mining to be more sustainable. Published on January 29, 2021, at https://www.semana.com/empresas/articulo/que-es-el-hidrogeno-verde-y-como-se-produce/301036/

21 Colombia must bet on green hydrogen. Published on January 12, 2021, at https://www.eltiempo.com/vida/medio-ambiente/colombia-debe-apostarle-al-hidrogeno-verde-560082

In Paraguay, the objective of the "Road to Green Hydrogen (H_2)"[22], project is to promote the use of H_2 in the country and to promote the green hydrogen economy in the country. It has three phrases: - Acquisition of knowledge; - Expansion of the Project for increasing the capacity for generating H_2 and – Consolidation of the use of H_2 in Paraguay. This initiative responds to the directives of the National Energy Policy. It is coordinated by the Vice Ministry of Mining and Energy of the Ministry of Public Works and Communications. Moreover, it is at the design stage of two pilot plants[23] of hydrogen production. With these plants, they set out to address a demand that comprises a transport system of three buses with 300 km of autonomy apiece, and light sedan-type and utility vehicles.

Paraguay, together with Uruguay and Germany, are developing the TRES project: a Triangular Cooperation Project of Affordable and Sustainable Energy for Paraguay: Implementing the National Energy Policy– Triangulating Affordable Energy. The objective of TRES is a greater development in both countries, two very important areas: alternative energies and energy efficiency. In order to materialize Action Line 1 on renewable energies, two technical consultancies are contemplated: for the "Analysis of technical and economic aspects for the development of a hydrogen economy in Uruguay and Paraguay" and the "Analysis of the required safety aspects for the installation of a hydrogen production plant, storage, use on vehicle units and also for supply points for vehicles", where the participation of the leading European companies in these areas is expected[24].

Moreover, other consortia and cooperation also stand out: between Germany and Chile, Germany and Brazil, Brazil-Chile and Mexico-Chile, and the regional initiative of the Ibero-American Science and Technology Program for Development (CYTED) aimed at having "the Ibero-American scientific community know the new scientific-technological developments related to H_2".

CYTED, created by the governments in order to "promote cooperation on issues of science, technology and innovation for the harmonious development of Ibero-America", considers that, given the increase of interest in hydrogen, it is necessary to have emergent frameworks and an infrastructure for scientific-tech-

22 Project "The Road to Hydrogen (H_2) in Paraguay". Published on July 23, 2020 at https://www.ssme.gov.py/vmme/index.php?option=com_content&view=article&id=2020:proyecto-qla-ruta-del-hidrogeno-h2-en-paraguay&catid=96:sample-news&Itemid=552

23 The Vice Ministry of Mining and Energy is presented the preliminary guidelines for the Project "The Road to Green Hydrogen in Paraguay". Published on July 31, 2020. At https://www.ssme.gov.py/vmme/index.php?option=com_content&view=article&id=2023:presentan-al-viceministro-los-lineamientos-preliminares-para-el-proyecto-laruta-de-hidrogeno-verde-en-paraguay&catid=96:sample-news&Itemid=552

24 TRES Project for the Triangular Cooperation among Paraguay, Uruguay and Germany. Published on July 10, 2020. At https://www.ssme.gov.py/vmme/index.php?option=com_content&view=article&id=2017:proyecto-tres-de-cooperacion-triangular-entre-paraguay-uruguay-y-alemania&catid=96:sample-news&Itemid=552

nological developments inherent to a Network-like project cooperation[25] for the Ibero-American Region. Hence, at the beginning of 2021, it approved the project "Hydrogen network: production and uses in transport and the electric sector (H2TRANSEL[26])" presented by a consortium of universities, companies and government organizations, led by Argentina.

[..] it is necessary to have emergent frameworks and an infrastructure for scientific-technological developments inherent to a Network-like project cooperation for the Ibero-American Region.

The consortium is formed by more than 40 groups of 13 Ibero-American countries: Argentina, Brazil, Chile, Colombia, Cuba, Ecuador, Spain, Mexico, Panama, Paraguay, Portugal, Uruguay and Venezuela.

In 2007, CYTED had approved the project on "hydrogen: production and purification; storage and transport (h2ppat[27])", also led by Argentina.

Below is a description and analysis of the situation of the countries with the greatest advancement and/or with the greatest perspective for development in the short term in the green hydrogen industry, its use and commercialization: Argentina, Brazil, Chile, Costa Rica and Mexico.

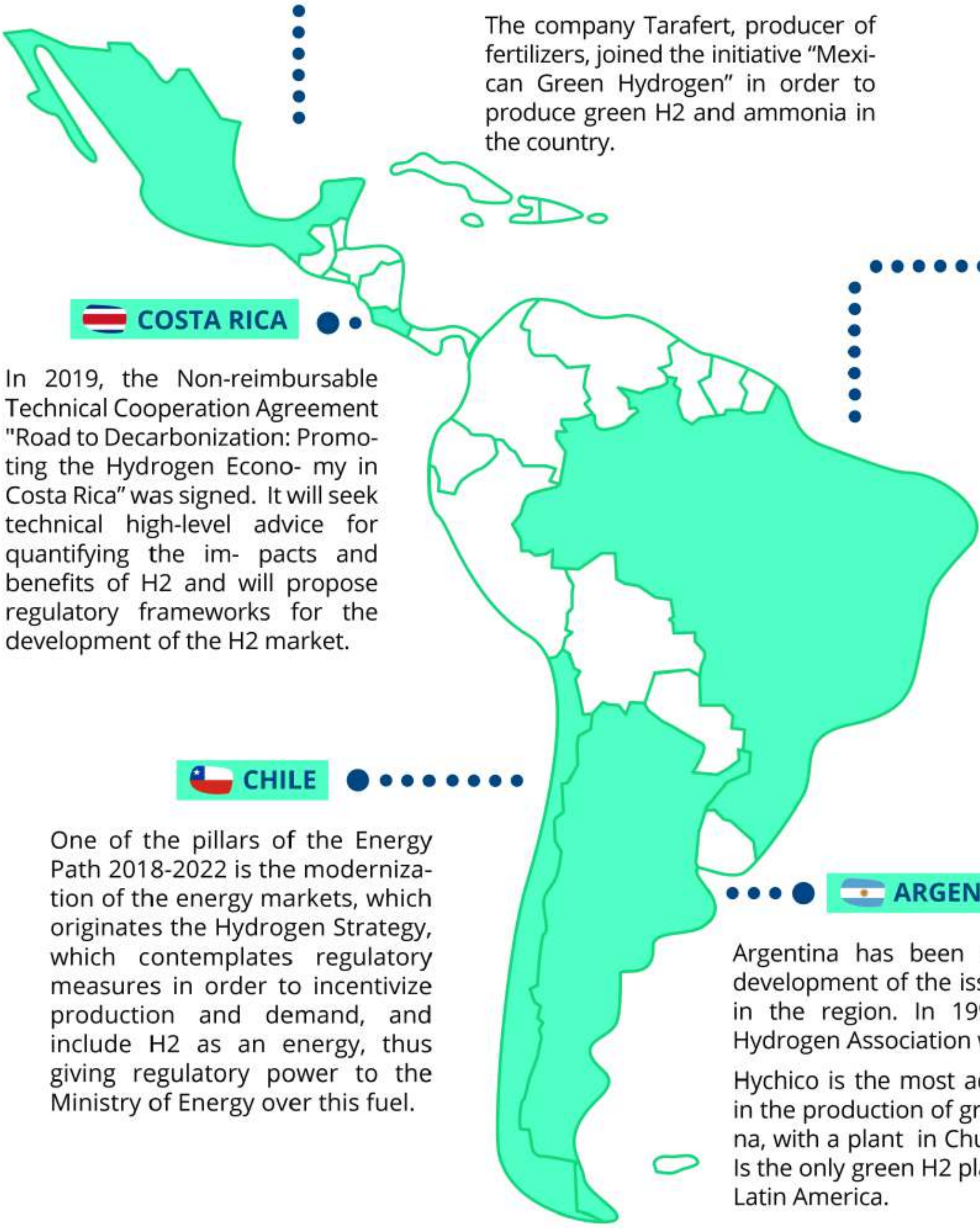
25 See: https://ithes-uba.conicet.gov.ar/cyted-aprobo-el-proyecto-de-red-hidrogeno-produccion-y-usos-en-el-transporte-y-el-sector-electrico-h2transel-presentado-por-un-consorcio-de-universidades-empresas-y-organismos-de-gobierno-lidera/

26 See: http://www.cyted.org/?q=es/detalle_proyecto&un=1025

27 See: http://www.cyted.org/?q=es/detalle_proyecto&un=357

GREEN H_2 IN LATIN AMERICA COUNTRIES: INITIATIVES AND PROJECTS

The countries, still with different degrees of progress, are implementing initiatives to define hydrogen as an alternative to achieve their commitments of emissions and the carbon-neutrality of their economies.



MEXICO

The company Tarafert, producer of fertilizers, joined the initiative "Mexican Green Hydrogen" in order to produce green H2 and ammonia in the country.

COSTA RICA

In 2019, the Non-reimbursable Technical Cooperation Agreement "Road to Decarbonization: Promoting the Hydrogen Econo- my in Costa Rica" was signed. It will seek technical high-level advice for quantifying the im- pacts and benefits of H2 and will propose regulatory frameworks for the development of the H2 market.

BRAZIL

The company Enegix Energy will construct what could be the largest green H2 plant in the world in Ceará, in the north of Brazil.

In February 2021, the government, Universidade Federal and the Federação das Indústrias of Ceará and the Complex of Pecém, signed a Decree to establish public policies for renewable energies and and for the formation of a Green H2 HUB.

CHILE

One of the pillars of the Energy Path 2018-2022 is the modernization of the energy markets, which originates the Hydrogen Strategy, which contemplates regulatory measures in order to incentivize production and demand, and include H2 as an energy, thus giving regulatory power to the Ministry of Energy over this fuel.

ARGENTINA

Argentina has been a pioneer in the development of the issues related to H2 in the region. In 1996 the Argentine Hydrogen Association was founded.

Hychico is the most advanced company in the production of green H2 in Argentina, with a plant in Chubut, in Patagonia. Is the only green H2 plant in operation in Latin America.

In order for these iniciatives to advance:

- Green H2 must be regulated as source of energy.
- The normativity must explicate the environmental risks associated with its production, uses, storage and transport.

3.1 Argentina

Argentina has been a pioneer in the development of the issues related to hydrogen in the region. It has promulgated a law that considered it as a fuel and, more than ten years ago, started production of green H_2 in Patagonia. But, in spite of these advances, the thematic was not systematically part of the agenda of the following governments after the approval of the aforementioned law for the promotion of hydrogen of 2006, and, it has just been considered again in the current administration. Another aspect to be highlighted is the lack of official information and the scarcity of studies on the issue in the country. Most of the information available are press releases and constitute the basis for what is described below.

But, in spite of the fact that the country has implemented some initiatives for developing the hydrogen industry, so far, it has not carried out consistent public policies that promote the development of green H_2. The objective of the most important project, and the only one in the region, implemented in Argentinian Patagonia, is to become an exporter, among other reasons, due to the remoteness of the potential internal market, and the difficulties of access to it due to the scarcity of infrastructure to transport it. In favor of this location is the fact that, according to the International Energy Agency, both Chile and Argentina could generate green H_2 at a cost of 1,8 dollars per kilo and reduce it, at least in the case of Chile, to 1,2 dollars / kg, the best value worldwide (IEA, 2019 and the Ministry of Energy of Chile, 2020). Given the geographic closeness between the productive zones of both countries, those prices could probably be replicated in Argentina, but in order that it may take advantage of this price condition, it is necessary to have the necessary infrastructure for its transport at their disposal, including the maritime routes, adapting the existing ports, building the corresponding normative and creating a favorable environment for the investor and one that is institutionally reliable as a provider.

One aspect that is relevant and which may delay the entry of Argentina into the green H_2 market, are its proved gas reserves (Vaca Muerta), whose use is much less costly than the one of renewable energies. This enables the country to migrate from black H_2 to gray H_2, and possibly to blue H_2, if financial resources are considered for having their disposal systems for the capture, use and storage of carbon, CAC. According to the International Energy Agency (IEA, 2019), blue H_2, with natural gas and CAC could be produced in Argentina at 1,9 dollars per kilo, a value very similar to those that green H_2 could reach.

According to the estimations of the company Hychico, owner of the Patagonian plant in Argentina, it would be necessary to invest 12 billion dollars among wind power farms, hydrogen production plants and liquefaction plants in order to produce 430 thousand tons of hydrogen per year, which is the estimated demand from the most developed countries in the next 10 years. Thus, considering that the price of hydrogen is of 5 dollars per kilo, the country would receive an income of 1,5 billion from exports[28]. But, according to experts, the success of the country in the field of hydrogen will depend on the costs of generation, production, logistics, storage and transport, which are almost entirely related to the economic stability and the trust that it may generate as a provider.

Argentina has not presented yet a proposal for the decarbonization of the country, but, according to its Environment minister, Juan Cabandié[29], in an interview with efeverde from December 2020, "the objective of reaching carbon neutrality by 2050 is "realistic". The country committed to presenting its long-term strategy in 2021. Moreover, the minister stated that "it is realistic, this needs a decision, it needs energetic attitudes on the part of those of us who have public responsibilities, it also needs the entire population, it needs a paradigm shift".

The report "Elements for a low-carbon long-term strategy" (FARN, 2020), posits the possibility that Argentina may reach carbon neutrality by 2050, but it underscores the fact that, in order to achieve it, the country will have to overcome barriers for its implementation: economic and financial ones, but also those imposed by the existing infrastructures and by the development and access to technologies, and, furthermore, cultural barriers, that it considers to be always difficult to address and overcome. The study includes among the range of combinations for obtaining neutrality, promoting hydrogen, electrification and biofuels.

In 2004, the draft bill[30] that creates the National Hydrogen Program was published. Two years later, in 2006, the law that would be the only one to regulate hydrogen as a fuel in the region (Law 26.123[31]). was published. This law sought to "promote

28 The Chilean project that threatens with delaying Argentina in the race for green hydrogen. Published on October 22, 2020, https://econojournal.com.ar/2020/10/el-proyecto-de-chile-que-amenaza-con-postergar-a-la-argentina-en-la-carrera-por-el-hidrogeno-verde/

29 Argentina sees as "realistic" the commitment to reach carbon neutrality in 2050. Published on December 15, 2020, at https://www.efeverde.com/noticias/argentina-ve-realista-el-compromiso-de-alcanzar-carbono-neutralidad-en-2050/

30 Art. 1.- establishes: We declare of national interest the research and development of the technology and production of hydrogen in all its phases: obtaining, storage and transport, as well as its consumption as a fuel and non-contaminating source of energy. Art. 4.- establishes: In order to ensure the financing of the National Hydrogen Program, we hereby create the National Promotion Fund for Hydrogen. Its resources shall be: 1") The National Administration Budget line destined specifically for the National Fund for the Promotion of Hydrogen. 2") Those generated with its activity. 3") Legacies and donations 49 Loans from national and international institutions and organizations.
See: https://www4.hcdn.gob.ar/dependencias/dsecretaria/Periodo2004/PDF2004/TP2004/04junio2004/tp069/3338-D-04.pdf

31 Promotion of Hydrogen. It is hereby declared of national interest. Date of sanction 2006-08-02. Published in the National

the research, development, production and use of hydrogen as fuel and energy vector, generated through the use of primary energy and regulates the leverage of its utilization within the energy matrix". It does not reference green hydrogen. In practice, given that its rules of application were never crafted, this law is inapplicable, and if it should not occur by the end of 2021, it will expire: Art.- 21 establishes the expiration of the regime at 15 years after its promulgation.

This Law, as well as the 2004 project, had established the creation of the National Fund for the Promotion of Hydrogen (Fonhidro), financed by the Government through a budget line from the national administration, set annually by the Congress, through loans, contributions, legacies and donations from individuals and legal entities, public or private national or international organizations and institutions, among others. It also establishes a "promotional" fiscal regime, enabling the projects to have benefits in terms of VAT payment and by the acquisition of capital assets or the execution of works related to its development. And hydrogen for vehicles would not be subject to the duties applied to liquid fuels, natural gas, diesel and the hydric infrastructure. To date, there are no precedents confirming the creation of Fonhidro[32].

In order to prevent the Law from expiring and losing its parliamentary status, which forces it to be submitted again to the Congress, a project was presented in April 2019 in order to postpone its expiration date by 20 and updating its text in order to place the focus on the production of green hydrogen. But, to date, there is still no decision regarding this initiative. According to the author of the above-mentioned draft bill, "the objective is to generate an incentive of a fiscal nature in order to compensate the greater cost required by this infrastructure, such as the exemptions on import tariffs, its inclusion within the fiscal regimes for the acquisition of capital assets for this activity to take off, as was the case with renewable energies".

In 2014, the National Hydrogen Plan[33]. was presented. With a budget of 42 million dollars and a deadline of execution of 16 years -the end of its implementation is expected for 2030-, it contemplated the creation of the National Hydrogen Center in the orbit of the Energy Secretariat, as an information center that would allow to coordinate the efforts from the universities, the technological institutes, and the National Institute of Industrial Technology (INTI).

Bulletin of Aug-25-2006. Available at https://www.argentina.gob.ar/normativa/nacional/ley-26123-119162

32 Can Argentina create a green hydrogen industry? Bnamericas. Published: Wednesday, November 04, 2020 https://www.bnamericas.com/es/reportajes/puede-argentina-crear-una-industria-del-hidrogeno-verde

33 See: https://www.unl.edu.ar/noticias/news/view/presentaron_en_la_unl_el_plan_nacional_de_hidr%c3%b3geno#.YGNmt69KiUm

As detailed on the website of Universidad Nacional del Litoral (UNL), the plan has 24 great projects to be implemented in the short, medium and long term. Thus, "seven projects are established for the short term (including the creation of the National Hydrogen Center[34]), eight for the medium term (possible injection of hydrogen into gas pipeline networks), seven for the long term (transport vehicles, collectives, human resources training, hydrogen production from the biomass) and two transversal ones. The latter are those that start in 2014 and end in 2030. One of them is for the international cooperation between bordering countries, and the other is the study and development of the social, cultural and environmental aspects of hydrogen. It has not been possible to find information related to the implementation of the Plan. But it would seem that it did not go into effect.

In 2019, the government signed a memorandum of cooperation with Japan, one of the great promoters of H_2 as a fuel and which was seeking providers to reduce the carbon footprint within its energy matrix. The initiative was sponsored by auto maker Toyota. However, the proposal did not move forward with the change of government, especially due to the economic recession and the crumpling of the automotive sector from the sanitary measures imposed in order to combat the Covid-19[35].

According to what Bnamericas[36], has published, the potential for exporting green hydrogen from Argentina could exceed 100 billion dollars, according to the calculations from the French electricity generator Engie. Moreover, it is estimated that businesses could be developed for close to 10 billion dollars in order to serve the internal market, especially in sectors such as mining, steel industry, transport and petrochemicals. The country's potential for the production of green H_2 can exceed the billion metric per year[37].

According to Miguel Ángel Laborde, member of the Board of Directors of CONICET, and the director of the Institute of Technologies of Hydrogen and Sustainable Energies (ITHES[38]), Norma Elvira Amadeo, meetings are currently being held in order to craft a new National Hydrogen Plan and to prepare a renewal of the Law of 2006[39].

34 At https://www.cnh2.es/

35 The Government seeks to promote "green" hydrogen as a new fuel in Argentina Through a number of subsidiaries of YPF, a consortium of companies was created in order to convert the country into a large-scale producer of renewable hydrogen. Published on November 27, 2020, at https://ithes-uba.conicet.gov.ar/el-gobierno-busca-impulsar-el-hidrogeno-verde-como-nuevo-combustible-en-la-argentina-%EF%BB%BF-a-traves-de-una-de-las-filiales-de-ypf-se-creo-un-consorcio-de-empresas-para-convertir/

36 Can Argentina create a green hydrogen industry? Published on November 04, 2020, at https://www.bnamericas.com/es/reportajes/puede-argentina-crear-una-industria-del-hidrogeno-verde

37 At https://h2lac.org/argentina/

38 Universidad de Buenos Aires-CONICET

39 Argentina promotes a National Green Hydrogen Plan. Published on February 22, 2021, at https://portalmovilidad.com/argentina-impulsa-un-plan-nacional-de-hidrogeno-verde/

Like Chile, Argentina could reach very low ranges of potential hydrogen prices. Given its capacity for generating clean electricity from wind in Patagonia and solar in the country's center and northwest. The factors of the wind plants can reach more than 60% in Patagonia, and solar ones more than 40% in the summer, country's center and west (CAMMESA, 2020).

The current capacity for generating clean energy by Argentina should reach 20% of the total matrix by 2025 in order to comply with Law 27.191 on renewables, and this proportion is considered to be sufficient to promote the local hydrogen industry in a first stage, focused on public transport. Between the year 2002 and January 2021, the total national installed power was almost doubled, growing from close to 24 thousand MW to the current 42 thousand MW. From these, according to the source, 25,3 thousand are thermal, 10,8 thousand are hydric, 4,1 thousand are renewable (2,7 thousand wind, 759 solar, 510 hydric, 57 biogas and 54 biomass) and 1,7 thousand are nuclear. The installed power from renewable sources represented 10% of the total (CAMMESA, 2021).

Since 2016, when the first renewable energy plants were implemented in the country, 2,6 thousand GWh were generated. In 2020, the amount was almost 13 thousand GWh (CAMMESA, 2021).

Between 2016 and 2019, the government adjudicated rates in biddings for 6,5 gigawatts of capacity for renewable energy and contributed to making wind and solar energy the most economic non-subsidized sources in the country. When these projects are fully operational, renewable energy will provide 18% of the total electric supply of Argentina[40].

But the country has two additional advantages: an ample experience of the industry which, for the last 60 years, produces ammonia for manufacturing fertilizers and a high experience in the handling of high-pressure compressed gases.

Moreover, Argentina has two systems for the transport of gas: the transport main routes operated by Transportadora de Gas del Norte and Transportadora de Gas del Sur, which add up to a total of 15.923 km of gas pipelines and 1,164 million HP of installed power. The total capacity of transport, considering the current one plus the expansion works underway, is of 155,8 million m^3 /d. These two main routes have eight interconnections with neighboring countries: two with Uruguay, one with Brazil, four with Chile and one with Bolivia. This infrastructure, though old -more than 40% of the pipes and more than

40 See https://www.abo-wind.com/es/compania/internacional/argentina.html

15% of the installed power are more than 40 years old- could be used in order to transport the hydrogen inside the country, into the neighboring countries and to the ports for consumers from Europe and Asia. (IAPG, 2015[41]).

Regarding hydrogen, currently, with a demand for somewhat more than 300 thousand tons per year, its use is mainly industrial. The sectors with greatest use are the petrochemical, for the processes in the refineries, and the chemical industry, for the production of ammonia and fertilizers for agriculture. The company YPF produces «gray» and «blue» hydrogen (one, a natural gas and the other produced through non-renewable procedures, but low on carbon), consumes them on site as a part of its hydrocarbon operations, and these constitute 36% of the total production in Argentina[42].

For the business development manager of the Argentinian unit of Air Liquide, today, all the conditions are in place for generating hydrogen in the country at a cost equal to, or lower than, that of diesel, which would make its implementation viable in transport[43].

However, it is estimated that it would be necessary to improve the infrastructure for the transport of H_2 in order to be able to distribute it throughout the country, for which it would be necessary to analyze the possibility of using the current gas pipelines or building new ones, which requires having access to external financing. But this is not happening yet. According to the publication from Bnamericas, so far, Argentina has not requested any of the credit lines made available by the IDB for projects connected to hydrogen, stated the advisor of the head of the entity's energy division[44].

Given the new interest of the country regarding hydrogen, the government commissioned Y-TEC[45] to lead the development of a platform (H_2Argentina Platform) to promote a collaborative work among companies that will allow to innovate and promote a sector with a key future projection. Thus, Y-TEC, a technological research company controlled by the state-owned oil company YPF

41 Argentinian Institute of Oil and Gas (IAPG), 2015. From Vaca Muerta to the home of Argentinians. The challenge of gas downstream in Argentina. Available at https://www.iapg.org.ar/download/Downstream.pdf

42 See https://h2lac.org/argentina/

43 Can Argentina create a green hydrogen industry? Published on November 04, 2020, at https://www.bnamericas.com/es/reportajes/puede-argentina-crear-una-industria-del-hidrogeno-verde

44 Can Argentina create a green hydrogen industry? Published on November 04, 2020, at https://www.bnamericas.com/es/reportajes/puede-argentina-crear-una-industria-del-hidrogeno-verde

45 Through one of the subsidiaries of YPF, a consortium of companies was created in order to convert the country into a large-scale producer of renewable hydrogen. By Andrés Sanguinetti, published on July 09, 2020, at https://ithes-uba.conicet.gov.ar/el-gobierno-busca-impulsar-el-hidrogeno-verde-como-nuevo-combustible-en-la-argentina-%EF%BB%BF-a-traves-de-una-de-las-filiales-de-ypf-se-creo-un-consorcio-de-empresas-para-convertir/

(51%) and the national council on research Conicet (49%)- launched Consorcio H_2ar, which will work in the next two years on the study of scenarios for the production, transport and export of renewable hydrogen, as well as the assessment of specific application opportunities in the fields of transport, industry, the natural gas network and electric energy.

The Consortium[46] is defined as a collaborative workspace among companies that are acting, or that are interested in participating in the hydrogen value chain, from production to application. The first point where it intends to work is the use of hydrogen for public transport, both for the propulsion of the vehicle and for the electric production for secondary services such as air-conditioning and the communications and electromechanical systems.

46 See https://y-tec.com.ar/consorcios-id/

Current situation: current initiatives and initiatives being developed

The advances in Argentina on the issue of hydrogen date from the beginning of the 1990s, with the first experimental plant built at Pico Truncado, located in the province of Santa Cruz and, with the work of a group of professionals who drove this agenda, mostly concentrated in the Argentinian Hydrogen Association (AAH). The Association was created on the initiative of Universidad Nacional de la Plata and with the presence of participants from the hydrogen Seminar conducted in the city of Buenos Aires in 1996. In the same year the Argentinian Association of Wind Energy (AAEE) was founded with some common referents. The Association, though it does not mention explicitly green H_2, it contemplates among its objectives: contributing to the recovery and preservation of the environment; especially in large cities, for which the need for developing energy systems that are sustainable and pollution-free is imperative, as well as promoting actions that aim at the dissemination of the use of clean energies (See: https://www.aah2.org/).

It also seeks to promote the linkage and coordination among government sectors, industries, research and development institutions and universities, for the establishment, at the national level, of the hydrogen industry, and its later growth.

Currently, the municipality of Pico Truncado and the Energy Institute of Santa Cruz seek to resume and start service at the installations, which have been closed for many years. It was inaugurated in 2005. It is estimated that, once an experimental stage is completed, the project will move on to its semi-industrial phase[47]. It belongs to the municipality and 20 million pesos are required for its reactivation. Its financing could come from the income for the renovation of petroleum areas with YPF, if the project applied, or through the mining royalties coming from the cement factory that it operates in the city[48].

Hychico[49], is the most advanced company in the production of green hydrogen in Argentina, with a plant located in the surroundings of its oil exploitation area and its Diadema[50] en la provincia de Chubut en la Patagonia. wind farm in the province of

47 They want to reactivate the hydrogen plant of Pico Truncado. Published on October 30, 2020, at https://www.revistapetroquimica.com/quieren-reactivar-la-planta-de-hidrogeno-de-pico-truncado/

48 Pico Truncado looks for 20 million in order to complete its experimental hydrogen plant. Published in El Caletense on February 23, 2021. At https://www.elcaletense.net/detalle/4985/Pico-Truncado-busca-20-millones-para-terminar-su-planta-experimental-de-hidr%C3%B3geno

49 See http://www.hychico.com.ar/esp/index.html

50 Diadema Wind Farms (6,3 MW) and Diadema II (27,6 MW).

Chubut in Patagonia. This project implemented in 2008 is the only green hydrogen plant in operation in Latin America. It is controlled by the national oil company Compañías Asociadas Petroleras S.A., incorporated in 2006 in order to operate and maintain wind farms and hydrogen production plants from water electrolysis in Argentina. It has two electrolyzers with a total capacity of 120 Nm^3/h of hydrogen and 60 Nm^3/h of oxygen. It is conducting assays on hydrogen transport at the local and international level. To that effect, it has built a duct of 2,3km from its plant to a well, where another project is being developed, for the underground storage of hydrogen in reservoirs depleted from oil and gas.

More recently[51], and the company TCI Geogroup signed an agreement with the objective of starting studies of technological and economic feasibility for introducing the hydrogen technology in its ship fleet, either through blending with natural gas in existing engines, such as the propulsion by fuel cells or by hydrogen in future vessels or for modernizing the existing ones. Likewise in its auxiliary operations on land and port logistics. The managers from TCI Gecomp pointed out that they expect to develop the first stage as of next year and have the first applications operating based on hydrogen before 2025.

ABO WIND[52], a company with German capital, is analyzing the development of hydrogen projects in Argentina. Currently, it has a portfolio of 20 projects divided almost equally in wind and solar developments, and to expand its offer with hydrogen.

51 Renewable energies: the company Buquebus starts studies for introducing hydrogen in its fleet. Published on November 24, 2020, at https://biodiesel.com.ar/14934/energias-renovables-la-empresa-buquebus-inicia-estudios-para-introducir-el-hidrogeno-en-su-flota

52 ABO WIND analyzes incorporating green hydrogen projects into its portfolio for Argentina. Published on November 12, 2020. By Nanda Singh, at https://www.energiaestrategica.com/abo-wind-analiza-incorporar-proyectos-de-hidrogeno-verde-en-su-portfolio-para-argentina/

3.2 Brazil

It is estimated that Brazil will become an important player in the global green hydrogen industry thanks to its high competitiveness in the generation of wind and solar energy (once it is massified) and thanks to the easy access to the Atlantic, to important consumer markets, especially encouraged by the green recovery plans of the European Union. The country is capable of producing hydrogen in different regions either for generating electricity or for supplying thermal charges (heating) in order to serve the industrial activity, such as the manufacture of cement and fertilizers.

Brazil is part of the International Association for the Hydrogen Economy (IPHE), and has defined some policies directed at the research and development of fuel cells and hydrogen, such as the Science, Technology and Innovation Program for the Hydrogen Economy (ProH_2), of the Ministry of Science and Technology and the Brazilian Roadmap for the Structuring of the Hydrogen Economy of the Ministry of Mining and Energy (Andrade and Lorenzi, 2015). Though not as a public policy, in 2017 was founded the Associação Brasileira de Pesquisa, Desenvolvimento e Inovação do Hidrogênio (Brazilian Hydrogen Association, ABH_2) destined to the research on hydrogen in Brazil.

Moreover, hydrogen has become a part of the Brazilian energy strategy, defined in the National Energy Plan 2050 (Ministry of Mining and Energy, 2020), which considers it to be an element of interest in the context of the decarbonization of the energy matrix. Brazil assumed commitments within the framework of COP 21, such as the one for its energy matrix to conform to 45% of renewable energies by 2030, increasing to 18% the quota of sustainable bioenergy by the same year, aside from expanding the use of non-hydric renewable sources in the energy and electric matrix and continuing as the improvement of the efficiency of the electric sector. It promised to reduce emissions by a 37% by 2025, in comparison to the levels of 2005. It also established the objective of reducing to zero the illegal deforestation by 2030 and reforesting 12 million hectares in the Amazon.

The updated version of NDC[53] presented in 2016 increases the goal of reducing emissions by 43% and extending the deadline for its compliance, from 2025 to 2030, and established the indicative objective of achieving climate neutrality –that is to say, zero net emissions– in 2060. This objective, however, could be reviewed in the future, depending on the functioning of the market mechanisms of the Paris Agreement, without discarding an even more ambitious long-term strategy. Its compliance is conditioned on whether the country can collect, as of the year 2021, 10 billion dollars per year from other countries.

A key aspect that will allow Brazil to advance more rapidly: according to the results of the mapping of stakeholders with international organizations, conducted by the Brazil-Germany Chamber of Commerce, 80% of the German companies involved in the supply or consumption of H_2 have representations in Brazil and 95% of the companies from the Global Hydrogen Council have subsidiaries in the country. Hence, it is warranted to suppose that Brazil can reach, very rapidly, a state-of-the-art technological status, given that what is being done in relation to H_2 in the world could be easily replicated in the country by already existing companies.

However, from the countries analyzed here, Brazil is the one that has the least chances of taking advantage of the momentum that green H_2 is creating and that countries like Chile have been able to leverage to its fullest extent. Even though, like Argentina, Brazil has delved precociously into the thematic of hydrogen as energy, it is estimated that the current slowness with which it is entering the debate over green hydrogen is connected to its energy matrix and, to a great extent, due to the use of biofuels in the transport sector (biodiesel and ethanol). The energy matrix, although essentially renewable, is considered to be one of the most important obstacles for the adoption of green hydrogen in Brazil due to the great diversity of clean sources that the country already possesses, including in this list the studies on ethanol fuel cells, a great competitor for the commercial entry of hydrogen into the country. Moreover, the volume of national norms and patterns related to the use of hydrogen as energy is insufficient, which forces the country to also advance rapidly to the effect of correcting these flaws.

53 Brazil's Nationally Determined Contribution (NDC). Available at https://www4.unfccc.int/sites/ndcstaging/PublishedDocuments/Brazil%20First/Brazil%20First%20NDC%20(Updated%20submission).pdf

Some aspects to be considered regarding the Brazilian reality and its potential as a producer and consumer of green H_2

The national market for hydrogen energy outside the industrial sector is not large, and even in the long term changes are not expected. In the transport sector, H_2 will have to "contend" with vehicles powered by biofuels, resulting from a long policy of fuel change promoted by the state for the last five decades, with hybrids and then electric, the new trend of the automobile industry. One cannot forget the importance of Brazil as a producer of cars, buses and trucks. But, as we will see further on, the country already has human resources and laboratories capable of dominating strategic niches and, therefore, participating in the production of components and supplies for equipment of pure generation of hydrogen or of energy, be they fuel cells, chemical or biological processes.

Another advantage for Brazil is that, like Argentina, it has a long experience in the manufacture of fertilizers, although 75% of the offer is imported (ANDA, 2019[54]) and, therefore, hydrogen is an element that is widely known by the local industry.

For each scenario, gray, blue or green, the country has strengths and opportunities:

For gray hydrogen, the key is natural gas. Brazil has large proven reserves that are scarcely explored, as they have not been a priority, but which now receive special attention on the part of the government. Therefore, with investments that can be for the most part private, producing gray hydrogen in large quantities is not a challenge in the mid and long term (Lameiras, 2019).

The availability of gas pipelines is one of the country's advantages for producing, consuming and exporting H_2. Its grid of gas pipelines allows it to transport gas along the Atlantic coast, interconnecting their main consumption centers and accessing its most important maritime ports. As commented further along, the National Energy Policy 2050, considers the possibility of mixing hydrogen on natural gas pipelines, thus promoting its use. However, in an ever closer future, the most important markets they will no longer be interested in gray hydrogen. All eyes are on green h ydrogen.

54 Principais Indicadores do Setor de Fertilizantes. Available at https://anda.org.br/wp-content/uploads/2019/11/Principais_Indicadores_2019.pdf

For the production of blue hydrogen, there are two lines. The first one is in the process of capturing carbon. This line is uncertain, because it requires a large capacity for investment and storage or use of carbon dioxide emitted. However, although it is feasible to produce close to the place where petroleum is extracted or in areas with aquifers, these problems can be solved. The second line for the production of blue hydrogen is the use of renewable raw materials, biomass or biogas, for example, by using energy sources that do not emit greenhouse effect gases. For this line, Brazil has a great potential, because it has ample biomass resources, as well as options for clean energy generation (Lameiras, 2019).

For green hydrogen, the country also has great advantages and strengths, but in order to leverage them it is necessary to have cheap and abundant energy, which, in the short and mid-term is still far from being achieved.

For green hydrogen, the country also has great advantages and strengths, but in order to leverage them it is necessary to have cheap and abundant energy, which, in the short and mid-term is still far from being achieved because it would be necessary to have investments in the generation of clean energies at very high levels, which, even if achieved, would generate, especially in an early stage, a product whose costs would not be commercially competitive.

Another relevant issue that could delay the entry of Brazil into the green H_2 market is related to the availability of electricity and, at the same time, the deployment of other clean sources in the electric matrix. In spite of the fact that the electricity produced and consumed in the country is mostly hydric (58,8% of the total installed capacity in 2020) and that wind power is already the second most important source (10,3%), several studies observe that, in order for the country to recover the growth losses of the last years, and which were accentuated by COVID-19, the hydrologic system will not be sought and wind and solar energies, aside from the limitations due to their intermittence, they are still too expensive, which has affected, in particular, the takeoff of the latter.

In light of these scenarios, it is very probable that the country may have to appeal to the thermal power plants and power generators. If Brazil were to grow by more than 3,5% per year, for three or four consecutive years, it is estimated that there will be a reset in the system due to the deficiency in the infrastructure, mainly logistical, and in order to supply electric power (M8, 2020), which will accentuate even more, in the face of climate situations such as the reduction in rains and “abnormal” periods of drought which would impact generation. Demand would jump from the current 474TWh (EPE, 2020) to 680TWh (M8, 2020). And the total offer, which, in 2019 reached 626,4TWh, in order to accompany such growth rates, would have to reach 942TWh (M8, 2020).

The current installed capacity amounts to 170 TW and it grew by 40% between 2012 and 2019. In the coming years it was expected to grow by 13%. But according to experts, these investments not only do not allow to reach the necessary offer in order to enable the recovery of the national economy, but if these were to be advanced, the country would not have the resources for its realization. The national planning studies completed in August 2020 (EPE, 2020) recommended originally a total investment of 109 billion Reales for the transmission, by the horizon of 2030. From this total, 49,5 billion Reales pertain to projects that have not been granted yet. As of 2023, in an optimistic scenario, it is considered that all of these resources be invested until 2030. But in a pessimistic scenario, the investments would decrease almost down to a half (59,2 billion Reales). The difference between both scenarios are precisely the installations still not granted. That is to say, there is no clarity as to whether these projects will be effectively be carried out. The uncertainties associated to the context of the COVID pandemic (EPE, 2020a) were also considered.

Another aspect to be considered is the lack of a clear policy related to the expansion of the offer of renewable energies in the country. As a way of attenuating the impacts of the electricity crisis of the year 2001 and promoting the expansion and competitiveness of the system, Brazil created the Alternative Sources Incentive Program (Proinfa) which offered complementary credits through the Energy Development Account (CDE) for energy generation. In order to participate in the concession of electricity generation, the agents had to follow the model of pricing “modesty”. The criterion was the lowest rate for the commercialization of the electricity produced.

Thus, 131 projects were implemented: 52 wind power farms, 60 PCH[55] and 19 thermal to biomass energy projects, which, all together, generate 11,2 million MWh, adding 2.975 MW of installed power.

55 Small Hydric Plants

This program promoted the incorporation of wind energy, mainly, and, although it was the basis for the unconventional renewable energies incentive program, some years later, having complied with the goals defined in its first stage, the program was deactivated and today the initiatives related to the issue pertain to the traditional processes used by the Brazilian State for these purposes.

Even with these limitations, wind energy has now become the second most important source of electricity in Brazil, behind hydroelectric. The installed capacity of wind energy now exceeds 16GW with 637 farms and 7.738 wind turbines, according to data published by the industrial association Abeeólica. In 2019, the average plant factor in the country reached 43%, well above the world average of 34%. The majority of the capacity is in the northeast zone, where this source is responsible for 89% of the electricity supply. It is forecasted that the capacity will grow up to 24,2GW by 2024, considering only the projects already contracted through the energy auctions of the government and the contracts of the unregulated electric market. Wind has expanded as an energy in the country during the last decade, as in 2010 it only contributed 928MW (bnametricas, 2020[56] and Abeeólica, 2019).

Regarding Hydrogen, Brazil has taken its first steps toward including it into the country's energy grid in the 1970s since the oil crisis, when government programs were created for the substitution of this fuel. Thus, in 1975, the Hydrogen Laboratory (LH_2) was founded. It is an independent research institution linked to the Physics Institute of Universidad Estadual de Campinas (UNICAMP), which centered its efforts on researching the production of H_2 for its use in combustion engines (Lameiras, 2019).

But, although initiatives related to hydrogen still continued after the crisis ended and the price of oil dropped again, almost all of the projects were discontinued, their resources were cut off and the majority of the laboratories were closed. However, LH_2 continued, though without resources, but through the infrastructure installed in the previous period, it continued to subsist through the sale of hydrogen to the chemical industry (Lameiras, 2019).

In 2001, as a result of the first Brazilian Conference on Hydrogen, the National Hydrogen Energy Reference Center was born (CENEH), whose objective was to gather and disseminate information related to the research and development of technologies related to the use of hydrogen as an energy (Andrade and Lorenzi, 2015).

56 Brazil reaches the capacity of 16GW of wind power. Published on June 16, 2020, at https://www.bnamericas.com/es/noticias/brasil-alcanza-16gw-en-capacidad-de-energia-eolica

The projects developed with the CENEH pertain to research related to the use of hydrogen as an energy, such as: hydrogen production through different sources (hydroelectric, ethanol, biomass, photovoltaic systems, wind power systems); development of fuel-cell systems; automotive systems; batteries; energy networks; energy efficiency, etc.

In 2002, the Brazilian Program for Fuel-Cell Systems (PROCaC) was launched, a program from the Ministry of Science and Technology (MCT) centered on the research of fuel cells, with the objective of organizing a research network and promoting actions integrated and cooperatives that allow the national development of fuel-cell systems technologies (Lameiras, 2019).

In 2004, the Ministry of Mining and Energy (MME), started crafting the Roteiro para a estruturação da economia do hidrogênio no Brasil. The study was launched officially in 2005 and its main objective was the introduction of the hydrogen economy in Brazil for 2025.

In 2005, the PROCaC was renamed as the Program of Science, Technology and Innovation for the Economy of Hydrogen ($ProH_2$). The $ProH_2$ contemplates among its objectives: "promoting the establishment of norms and patterns for the certification of products, processes and services related to the hydrogen and fuel-cell technologies".

This same year, the Ministry of Mining and Energy coordinated the so-called "Roadmap for Structuring the Hydrogen Economy in Brazil". The document established a timeline of 20 years for reaching the goals related to each theme proposed and prior to the launch of a Governmental Program of Production and Use of Hydrogen in Brazil after 2007, which, within the framework of the discoveries, at the same time as the deposits of oil and gas of Pre-Sal, did not materialize (EPE, 2021).

In May of 2009, the Center for Strategic Management and Studies (CGEE) published a full study on the hydrogen economy in Brazil.

But in spite of having developed these initiatives and that the country had the roadmap for structuring the hydrogen economy in Brazil launched in 2005, there was a new deceleration in the research related to hydrogen, this time mainly due to the global discouragement with the difficulties and the slow progress of technology (Lameiras, 2019).

In spite of this notorious slowdown in the interest over hydrogen, several technological projects continued to be developed in associations with universities and/or research institutes and companies, which succeeded in developing applications for the generation of hydrogen. Thus, from 2013 to 2018, 91 projects related to hydrogen and fuel cells were identified, which had access to resources equivalent to 7 million dollars of the year 2021 (EPE, 2021). Until 2007, before the discovery of the oil deposits of Pré-Sal, the investments had reached close to 25 million dollars (of 2021) (Andrade and Lorenzi, 2014).

As a result of the drive from R&D&D, the country stood out when in 2010 it put into circulation the first hydrogen bus with national technology developed by Universidade Federal do Rio de Janeiro (UFRJ). The initiatives from the years 2000 continued to yield some fruits and, more recently, the Genomics and Bioenergy Laboratory of UNICAMP and Nissan signed a contract for advancing in the development of cells that generate hydrogen from the gas obtained from reformed bioethanol, known as solid oxide fuel cells (SOFC) (Lameira, 2019). In turn, in 2020[57], the project developed by UFRJ presented the fourth version of the model presented in 2010, and is now in the pre-commercial stage. A study from the institution demonstrated that if all the fleet from BRT in Rio de Janeiro (Transporte Rápido por Ônibus) were converted to hydrogen, the cost of the new fuel would reach parity with diesel already by 2025.

Still in the field of R&D, within the Ministry of Mining and Energy, the research lines of the Electric Energy Research Center (CEPEL) on fuel-cell energy generation systems produced theoretical and experimental results (Lameiras, 2019).

In spite of these advances, according to the Institute of Electric and Electronic Engineers (IEE) of Brazil, in order for green hydrogen to be effectively developed, the country must confront the great challenge of implementing production chains, storage and transport and, although it has the technical conditions for developing technologies at the national level, it will be necessary to associate with other countries and multinationals for advancing in this issue. It needs international partners to hire technicians and train its professionals. For now, the country already has the cooperation of Germany and Chile[58].

57 Campo & negócios. Brasil tem potencial no hidrogênio verde. Published in September 2020, at https://campoenegocios.com.br/brasil-tem-potencial-no-hidrogenio-verde/

58 "The green hydrogen industry is getting stronger in Brazil". Published on March 19, 2021, at https://www.bnamericas.com/es/reportajes/industria-del-hidrogeno-verde-cobra-fuerza-en-brasil

With Germany (EPE, 2021):

- Within the framework of the Parceria Energética Brasil-Alemanha, they are developing the Estudo de Mapeamento Setorial do Hidrogênio Verde no Brasil, which seeks to identify the main agents involved today in the hydrogen value chain in Brazil and to offer a general vision of the main technologies for the production of green hydrogen and "Power-to-X" in the development of the country;
- Within the scope of the Projeto de Cooperação em Tecnologias para Armazenamento de Energia, a study is being developed for leveraging the production potential of green hydrogen in Brazil, in order to subsidize the development of a new path for the hydrogen economy in this country.

With Chile: composition of the Brazil-Chile Work Group for conducting a technical-exploratory work on the potential for bilateral cooperation on hydrogen, highlighting the interest of Chile in the local production of "green hydrogen" with investment intentions in this field, on the order of 200 billion dollars in the next 20 years (EPE, 2021).

In February 2021, the Energy Research Company, EPE[59], published a Technical Paper[60] where it addresses conceptual and fundamental aspects for the construction of a Brazilian hydrogen strategy. The document seeks to conceptualize the panorama of the hydrogen market, the technological paths and its generation processes. Moreover, it analyzes some factors that determine or trigger competitiveness and the main challenges the development of the market of hydrogen energy use in the country (EPE, 2021).

Previously, the EPE had already included green hydrogen as a key source for helping to satisfy the energy demand of the country in the future.

Moreover, in February 2021 the Conselho Nacional de Política Energética (CNPE) pointed at hydrogen as one of the priority issues for research and development in the country aimed at the application of public resources toward these goals (EPE, 2021).

59 Its purpose is to provide services to the Ministry of Mining and Energy (MME) within the field of studies and research destined to provide support to the planning of the energy sector, comprising electricity, oil and natural gas and its derivatives and biofuels. It is a public federal company, attached to the General Budget of the Union, created through a precautionary measure converted into law by the National Congress - Law 10.847 of March 15, 2004. It was implemented

60 https://www.epe.gov.br/pt/imprensa/noticias/epe-lanca-nota-tecnica-bases-para-a-consolidacao-da-estrategia-brasileira-do-hidrogenio-

Hydrogen is now part of the Brazilian energy strategy defined in the National Energy Plan 2050 (Ministry of Mining and Energy, 2020), approved in December 2020 by the Ministry of Mining and Energy. Indeed, hydrogen is pointed out as a disruptive technology and considered as an element of interest in the strategy within the context of the decarbonization of the energy matrix, the insertion of distributed energy resources, the search for the expansion of the forms of storage and management of flexibility, the perspectives of application of nuclear energy and natural gas. In the case of the transport sector and the implementation of electric transport, the Plan indicates as a technological perspective the application of fuel cells for the production of hydrogen from biofuels and gas (natural gas and biomethane).

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Another point considered in the PNE 2050 is the perspective of mixing hydrogen in natural gas pipeline networks in percentages and with limited pressures for transport and storage, as a better way of utilizing the gas pipelines and, at the same time, using important volumes of hydrogen for energy purposes. In the context of the decarbonization process and the perspectives of disruptive insertion of hydrogen, the PNE 2050 highlights as a recommendation for the energy policy:

- Stimulating the possibilities of the use of hydrogen for the decarbonization of sectors such as: transport, chemical industry, residential, as well as the generation of “clean” raw material for the industry, such as the steel industry, among others.

- Designing regulatory improvements related to quality, safety, transport infrastructure, storage, supply, incentive and use of new technologies.

- Articulating with other international institutions that have initiatives in the field of hydrogen.

Current situation: current initiatives and initiatives being developed

The green hydrogen market is taking shape in Brazil, at a time when there is a boom in local projects for generating renewable energy.

Among the outstanding initiatives that are being conducted, the one by the Associação Brasileira de Normas Técnicas (ABNT), which is discussing the standardization of hydrogen technologies, from production to end-use, within the framework of the Special Study Commission on Hydrogen Technologies - ABNT/CeE-067 (EPE, 2021).

Fortescue Future Industries (FFI[61]), a subsidiary of the Australia mining company Fortescue Metals, signed a memorandum of understanding with Porto do Açu, an important Brazilian maritime port and industrial center located in the state of Rio de Janeiro, in order to study the viability of installing a green hydrogen plant of 300 megawatts, with a potential for producing 250 thousand tons of green ammonia per year -a basic component of agricultural fertilizers-. The preliminary agreement was signed in late February 2021. The agreement also establishes the basis for the development of local solar and wind projects off the coasts of the states of Río de Janeiro and Espírito Santo.

Fortescue, a producer of iron ore, also announced that it plans to become carbon neutral by 2030 and that, as part of this objective, the company aims at producing green hydrogen at a commercial scale by 2023.

The plant to be built in Brazil will be driven by solar and wind energy. Among the possible partners of the project is Equinor ASA from Norway. They signed a separate memorandum of understanding, also in the month of February, in order to evaluate the construction of a solar plant in Açu. The port of Açu, is owned by Prumo Logistica SA, which is controlled by the private-capital United States company EIG Global Energy Partners.

61 Published on March 17, 2021, at https://www.mineria-pa.com/noticias/fortescue-construira-una-planta-de-hidrogeno-verde-en-brasil/

Also recently, Enegix Energy[62] has announced the construction of what could become the largest green hydrogen plant in the world in the state of Ceará, in the north of Brazil, after signing a memorandum of understanding with the state government. The Base One project will produce more than 600 thousand tons of green H_2 per year from 3,4 GW of renewable energy from base charge already contracted through an association with Enerwind. The initiative supposes an investment of 5,4 billion dollars.

The company chose this location for its strategic position for accessing the main international markets through the Atlantic Ocean, and for the availability of the clean energy sources that characterize this state in the north of Brazil. The project will be installed in the Port of Pecém, which has the adequate infrastructure for handling this type of fuels and access to water for the electrolysis process.

Within the framework of this initiative, the government of the state of Ceará, the Federação das Indústrias do Estado Ceará (FIEC), Universidade Federal de Ceará (UFC) and the Complex of Pecém (CIPP S/A), signed, also in February 2021, a Decree for setting up a Work Group whose purpose is to develop renewable energy public policies for sustainable development and for the formation of a Green Hydrogen HUB in the State of Ceará[63]. The HUB is located in the port of Pecém, in the metropolitan region of Fortaleza, the state capital. Pecém is the large-scale South American that is closest to Europa, which cheapens the logistics in comparison to other maritime terminals in Brazil and increases the country's competitiveness with other countries in the region. It is administered by the Dutch port of Rotterdam, the main entry gate for South American products in the European market.

62 Published on March 4, 2021, at https://elperiodicodelaenergia.com/enegix-energy-construira-la-planta-de-hidrogeno-verde-mas-grande-del-mundo-en-brasil/

63 https://www.pv-magazine.com/2021/03/03/brazil-may-host-5-4bn-green-hydrogen-plant/

3.3 Chile

Chile is probably the most advanced country of Latin America on the green H_2 issue regarding public policies. And its potential, which has been positioning it as a producer worldwide, is centered on some key aspects: institutional safety, economic and political stability and, perhaps more importantly, the country could produce this gas in a very cheap and competitive way, even considering the costs of transport to other continents.

A very short time ago, hydrogen was not considered as a fuel, but only as a chemical element, which limited its use, production, storage and commercialization. However, in February 2021, the country made a leap in relation to this issue. As of this date, this gas will be considered among the energy sources within the purview of the Ministry of Energy, as per the modification of Art 3 of Decree Law 2.224 of 1978, which created the Ministry of Energy[64].

This modification is framed within the scope of Law 21.305 on energy efficiency, promulgated on February 8, 2021. It materializes one of the pillars of the Energy Path 2018-2022, published by the Ministry of Energy in 2018 pertaining to the modernization of the energy markets, which, in one of its seven pillars, considers hydrogen within the "proposal for the organization of the legislation on hydrocarbons, which will incorporate the analysis of alternative fuels to be commercialized in the Chilean market". It implements the recent Hydrogen Strategy which, in its first stage, contemplates the promulgation of regulatory measures throughout its value chain, in order to incentivize production and promote demand, and it explicates the need for a modification of Decree with Force of Law 1 of 1979[65] and Decree Law 2.224 in order to include hydrogen as an energy, thus giving regulatory power to the Ministry of Energy over this fuel.

The regulation of hydrogen in Chile has 80 years, and in some cases it was surprisingly early, such as the reference to hydrogen vehicles in the Rules of Application, which sets dimensional and functional requirements for vehicles that provide urban collective locomotion services of 1991. According to specialist lawyer

64 At https://www.cne.cl/archivos_bajar/DL_2224.pdf and https://www.bcn.cl/leychile/navegar?idNorma=6857&idParte=8628649&idVersion=

65 At https://www.cne.cl/archivos_bajar/dfl1_1978.pdf

Augusto Quintana[66] (professor at the Law Department of Universidad de Chile), the fact that in Chile there is a "low normative density" over this matter does not imply that there are "loopholes" that prevent the development of hydrogen projects or, in its case, of pilot projects. In effect, due to the absence of specific norms, the general norms pertaining to fuels, gases, energy sources, etc., are applicable to hydrogen; and even an ample plurality of international technical norms. Nonetheless, it is necessary to have an update that is coupled with the current technology and that closes some of the loopholes in order to fully cover the lifecycle of H_2.

In countries like Chile, Australia and Saudi Arabia, renewable sources, both wind a solar, have a low levelized cost of energy (LCOE), which allows for high charge factors for hydrogen production through electrolysis. Therefore, they offer an optimum potential for producing renewable hydrogen at minimum costs. In these conditions, production could be available for around 2,5 dollars per kilo at the beginning of the 2020s, decreasing to 1,9 dollars per kilo in 2025, and maybe 1,2 dollars per kilo in 2030. If that were the case, these values would be way below the average for those of gray hydrogen, and even close to parity with the optimum costs of gray hydrogen in 2030, even considering those of CO_2 (IRENA, 2019).

Chile, according to the International Energy Agency (2019) could come to produce 160 million tons of green hydrogen annually, with a cost of less than two dollars per kilogram, with which it could not only ensure internal supply but it could become a great exporter of this energy resource. It also estimates that in the region of Magallanes, in the Chilean Patagonia, it is possible to produce almost 10 million tons of green hydrogen per year. In the north, IRENA estimates that, with the utilization of a small amount of the photovoltaic solar potential of the Atacama Desert, more than 450 thousand tons of hydrogen could be produced per year.

Chile's greatest advantages for producing green H_2 are closely related to the availability of energy resources throughout its geography, a variable that impacts directly its production costs (Ministry of Energy, 2020):

1. The north concentrates the highest solar radiation of the planet, with plant factors that could reach up to 35% in single-phase photovoltaic plants of one-axis segment.

66 Regulation of hydrogen: 80 years of normative history in Chile. Published on October 27, 2020 at https://www.revistaei.cl/columnas/regulacion-del-hidrogeno-80-anos-de-historia-normativa-en-chile/

2. Solar electricity generation in the central zone is more competitive than that from fossil energies. That is where the greatest urban and industrial consumption of the country is concentrated and, consequently, it has the greatest availability of distribution networks, logistic centers and closeness to ports and a great road network offer.

3. The winds from the extreme south allow plant factor on land that are equivalent to those in the sea of other countries. Wind turbines that are 120 meters tall, on land, can reach plant factors of 60%.

This combination of factors could reduce by 2025 the levelized cost of energy to values between 18 and 25 dollars / MWh, an amount at which it is expected that the production of green H_2 will compete with natural gas.

Not considering the costs of compression, transport and distribution, the green H_2 produced in the Atacama Desert and in the Magallanes region, could reach a levelized cost between 1,3 and 1,4 dollars/kg in 2030, and around 1 dollar per kilo in 2050: the lowest value worldwide, including lower than that of Australia, which could become its most direct competitor (Ministry of Energy of Chile, 2020).

A study commissioned by the Hydrogen Council to the consultant McKinsey (2020), analyzed the costs associated to the production and transport/distribution of H_2 and its future behavior. These three are the most important in the cost of the gas and, therefore, define the competitiveness of countries on this issue.

Since 2010, the electrolyzed costs have, have dropped by 60%, from between 10 and 15 dollars / kg of H_2 to the current 4 to 6 dollars / kg of H_2. In the case of long-distance transport, the principal means is maritime, and its cost is currently very high. However, it is estimated that, depending on demand, by 2030 it could be around 1,7 dollars /kg of H_2 and, for example, including the transport from Chile to thee USA, producing and transporting the H_2 up to the port of destination would cost 2,7 dollars / kg. Between Australia and Japan, the value of H_2 would reach 3,3 dollars / kg. Likewise, the costs of the local distribution have an important impact on the end-cost of hydrogen, and reducing them will also depend on demand. But, just as the value of long-haul transport, it is estimated that these would decrease by 60% if the transport is carried out by trucks, and by 63% if it is done by pipelines. The costs of local demand have an impact on the production decision in each economy (Hydrogen Council, 2020).

The considerations in relation to hydrogen are starting to become strong in Chile, under the auspices the Energy Path 2018-2022, published by the Ministry of Energy in 2018. Within the framework of the modernization of the energy markets, one of its seven pillars, hydrogen, is contemplated within the "proposal for the organization of the hydrocarbons normative, which will incorporate the analysis on alternative fuels to be commercialized in the Chilean market" and it is posited that it will be "studied as an alternative to conventional fuels in public transport" as a way of reducing the consumption of diesel and other fuels.

In countries like Chile, Australia and Saudi Arabia, renewable sources, both wind a solar, have a low levelized cost of energy (LCOE), which allows for high charge factors for hydrogen production through electrolysis.

Pillar 4 establishes as an objective the gradual but definitive construction of a clean energy matrix which allows a green and low-carbon growth. Although it does not promote the use of hydrogen as a source of electricity explicitly, by committing the country to initiate the process of decarbonization of the energy matrix through a timeline for the retirement or conversion of coal plants, it forces it to advance even more rapidly in the implementation of clean energies that may compensate the exit of this fossil fuel from the national electric system. This places Chile as an important player for the production of green H_2, whose basis is precisely the energy generated from clean sources.

Thus, in January 2018, an agreement was announced between the government and the partner companies of the Association of Generators of Chile, which has units that use coal, which contemplated three points: i) the companies commit not to initiate new coal projects if these do not have CAC or other equivalent technology; ii) creation of a new work group that analyzes, in the context of the Energy Policy of Chile, Energy 2050, the technological elements, as well as environmental, social, economic, those of safety and sufficiency of each plant and the electric system as a whole, in order to establish a timeline and the conditions for the programmed and gradual closure of the plants that do not have CAC or other equivalent technology, and iii) the Ministry of Energy will coordinate the group (Ministry of Energy of Chile, 2020a). The plan establishes the programmed retirement of the 28 coal thermal power plants functioning in Chile by 2040, with a first phase by 2024, of which eleven units that are equivalent to 31% of the installed capacity exit the system. The Plan, although it has undergone some modifications, has followed its course and the plants have been exiting the system according to plan.

In mid-2019, the decarbonization plan "Zero-Carbon Energy" was announces publicly, and the national goal of carbon-neutrality was set for 2050, which will imply a reduction of 65 million tCO_2e up to that date, according to statements from the minister of Energy[67].

In 2020, 15% of the installed capacity of electricity generation at the national level used coal as a source of energy and almost 40% of renewable energies, especially solar, wind and run-of-river hydric. Close to 33% of the electricity generated used coal and 31% used renewable sources (wind, solar and run-of-river hydric) (National Energy Commission[68]).

In 2019, the update of the Long-Term Energy Planning 2018-2022 (PELP), considered among the new challenges to be addressed in the next PELP, "modeling the new energy storage alternatives (hydrogen, short-lasting batteries, long-duration storage for arbitration purposes), as well as the technologies of generation, which are still incipient, such as tidal energy or hydrogen, and also the conversion of the current coal generating units, into low-emission alternatives" (Ministry of Energy of Chile, 2019).

In 2020, the government, understanding that the process of decarbonization of the national electric matrix is a reality and that it has been advancing as expected, that the country has a great potential of renewable energies equivalent to 70 times the national demand, and that the generation costs through clean sources, as well as the costs through electrolyzers, have been decreasing significantly, green hydrogen not only has become competitive, but it also opens business opportunities for the country. Thus, by late 2020, the Ministry of Energy of Chile (2020) published the Green Hydrogen National Strategy, which contemplated three "waves" or stages for the development of this new industry, which is estimated between 2025 and 2050, could reach the size of mining, one of the most important economic sectors of the country. The goal is that the country become, as of 2030, the leading global producer of green hydrogen by electrolysis.

67 The "Zero-Carbon Energy" Plan follows the advancement in order to reach decarbonization by 2040. Paper published on March 19, 2020, at http://www.infraestructurapublica.cl/plan-energia-zero-carbon-sigue-avance-alcanzar-la-descarbonizacion-al-2040/

68 https://www.cne.cl/estadisticas/electricidad/

In the first stage (2020-2025), the Strategy contemplates focusing on domestic large-scale consumption. It considers replacing imported ammonia with the local production and replacing gray hydrogen by using the country's refineries. Then, green H_2 will come to be used in passenger transport and long-haul heavy cargo. This stage contemplates the promulgation of regulatory measures throughout its value chain, in order to incentivize production and promote demand. A key issue, regarding regulation, contemplated in the strategy is the modification of the Decree with the Force of Law 1 of 1979 and Decree Law 2.224 in order to include hydrogen as energy source, thus giving regulatory power to the Ministry of Energy over this fuel. This was carried out in early 2021.

In the second half of the decade, the Strategy focuses on the extension of the use of green H_2 in local transport and on starting its export. It is expected that a more competitive production will displace the liquid fuels in land transport in new applications, such as mining, and gaseous fuels in distribution networks, for example. In parallel, there will be new opportunities for the export of green hydrogen and its derivatives to international markets. One of the drivers of this stage will be the attraction and promotion of consortia and the agreements to accelerate the export.

In the third wave, as of 2030, new markets will be opened to export in order to escalate production. The sectors of maritime and air transport may be decarbonized through fuels derived from hydrogen, both on local and international routes. The bet is that, as other countries will decarbonize, the export markets will grow.

In order to promote the internal market and exports, the government intends to launch a round of financing for 50 million dollars in order to leverage early and competitive projects of production and use of green hydrogen whose implementation will allow to reduce costs in the country.

The National Council on Green Hydrogen, created in 2018, together with the Ministry of Energy, will have the responsibility of carrying out the monitoring of the Strategy, coordinating the execution of the action plan and executing the update of this process every 3 years.

Current situation: initiatives being developed

Currently, there are at least four projects in different stages of implementation and there are agreements that have been signed with different international players, focused on producing green H_2 and its export. That is to say.

The most advanced project to date is a pilot plant whose formalities are being processed with the authority of the southern Region of Magallanes in order to obtain its construction permits. Highly Innovative Fuels (HIF), a subsidiary of the Chilean energy generating company Andes Mining & Energy (AME), the promoter of the initiative, presented, in November 2020 to the Environmental Impact Assessment System an Environmental Impact Statement (EIS)[69] for the "Pilot Project of Decarbonization and Production of Carbon-Neutral Fuels". The project presented (Pérez y Alvares Ingeniería y Proyectos, 2020), contemplates the construction of a chemical plant that will produce methanol (CH_3OH) and gasoline from carbon dioxide (CO_2) and hydrogen (H_2). Additionally, it considers the construction and operation of a wind turbine with a maximum power of 3,4 MW, next to the plant that will provide the electric energy to all its installations. It also considers the connection to the Magallanes electric system through the implementation of a medium-voltage electric transmission line (13 kV) of 8,8 km up to the plant as a backup connection. The installation will have an estimated production capacity of 3,9 tons per day of crude methanol, which will be distilled in order to produce approximately 2,5 t/day of methanol, of which up to 2,1 t/day will be destined to the production of 0,7 t/day of gasoline. The EIS also explains that the production process for the crude methanol contemplated by the project is divided into three phases: obtaining the carbon dioxide from the air, obtaining the hydrogen from water electrolysis (from a well and treated through a demineralization process) and synthesis of the methanol from the carbon dioxide and the hydrogen obtained previously.

For the pilot plant to be implemented, the electricity will be generated through wind, and a large part of it will be used in the electrolyzer that separates the hydrogen (H_2) and the oxygen (O_2). Through a filtering process, the carbon dioxide is obtained (CO_2) by capturing it directly from the air, which, through a synthesis process is combined with H_2, thus producing E-methanol (CH_3OH). In a second process, the methanol can be used for creating E-gasoline or it can be stored as a product. This way, the end-products from the Pilot Plant will be called synthetic fuels, and E-methanol and E-gasoline (Pérez y Alvares Ingeniería y Proyectos, 2020).

69 The full EIS is available at: https://seia.sea.gob.cl/expediente/ficha/fichaPrincipal.php?modo=normal&id_expediente=2149071179 and the project, at https://seia.sea.gob.cl/archivos/2020/11/18/0e6_Cap_1_Descripcion_de_Proyecto.pdf.

The project[70] contemplates an initial investment of 38 million dollars. It will receive a contribution of eight million euros from the Federal Ministry of Economy and Energy of Germany through Siemens Energy[71]. Grupo Enel will contribute focusing on wind energy and in the installation of an electrolyzer. It is expected to go into operation in 2022, which makes it, according to AME, the largest plant of its type for producing green hydrogen in Latin America. In later commercial stages, planned for 2024 and 2026, the capacity will increase to some 55 millions of liters per year and 550 millions of leaders of eFuels (gasoline) per year, respectively (Terram Foundation, 2020).

Porsche will buy all of the eCombustibles produced by HIF (Terram Foundation, 2020).

Other initiatives being developed:

1. Selkman Project, to produce hydrogen in Tierra del Fuego through wind energy, which will later be transformed into ammonia in order to be exported by ship to Korea, the United States and Germany.

2. HyEx Initiative, from Engie Chile and the company Enaex: strategic alliance to research the viability of the production of green ammonia from renewable hydrogen in the region of Antofagasta, north of Chile. Its objective is a solar farm de 2,000MW, which would feed a hydrogen electrolysis plant of 1.600MW for producing 124.000 tons of green hydrogen per year.

3. The Norwegian company Aker Clean Hydrogen and the Irish company Mainstream Renewable Power signed an alliance for exploring the development of the production of low-cost green hydrogen and ammonia in Chile, using the renewable energy generated by the portfolio of Mainstream wind and solar projects implemented in the country[72].

The mission of the National Council on Green Hydrogen, created in 2018 is to provide support to the ministry of Energy in order to craft a strategic, integral and ambitious vision for the production, use and export of green hydrogen, with a vision by the State to project it in the long term.

70 Emissions, water and dissemination: the doubts for the green hydrogen pilot in Magallanes. Published on 202/01/13, at http://generadoras.cl/prensa/emisiones-agua-y-difusion-las-dudas-para-el-piloto-de-hidrogeno-verde-en-magallanes

71 The hydrogen project in Chile: HIF receives financial support from the German government. Published on December 3, 2020, by Pilar Sánchez M., at https://www.pv-magazine-latam.com/2020/12/03/el-proyecto-de-hidrogeno-en-chile-hif-recibe-apoyo-financiero-del-gobierno-aleman/

72 Green hydrogen is in fashion: Aker Clean Hydrogen and Mainstream Renewable Power sign an alliance for production in Chile. Diario La Tercera, Published on February 19, 2021, at https://www.latercera.com/pulso/noticia/el-hidrogeno-verde-esta-de-moda-aker-clean-hydrogen-y-mainstream-renewable-power-firman-alianza-para-la-produccion-en

In 2018, moreover, the Chilean Hydrogen Association, H_2 Chile, was created as a trade association. It was founded by 28 individuals representing the private, public and academic sectors. Its objective is to promote the development of hydrogen as a sustainable energy vector, promoting its research, development and utilization in industrial, commercial, residential and transport applications. Currently, it has 23 partners, mostly from the energy sector[73].

According to H_2 Chile[74], Chile, together with other countries, allotted itself a fund of 10 million euros from the European Commission's "Fuel Cell and Hydrogen Joint Undertaking" (FCH JU) for the development and promotion of various green hydrogen projects and studies. The particularity of this allotment is that it has been destined to the Green Hysland project, which gathers several nations to deploy green H_2 initiatives, exclusively in island territories. The project will be developed between 2021 and 2025, and the pre-feasibility studies could contemplate Chiloé or another insular territory with similar characteristics, where green hydrogen and its multiple derivatives could be used for intensive aquaculture and agriculture journeys. Chile must still complete formalities to have access to these resources and, once these are available, it will be decided as to how these pre-feasibility studies will be developed.

Among the agreements signed by the country to date, the following stand out:

1. Arichile European-Chilean Alliance: ARICHILE H_2[75], under the European program INNOWWIDE, for producing green hydrogen in Magallanes, with a prototype of 1 MW, through a novel electrolysis system that can be supplied with sea water.

2. Energy Alliance between Chile and Germany[76]. Started in 2019, its members are the Ministry of Economy and Energy of Germany (BMWi) and the Ministry of Energy of Chile. It is a platform that supports high-level intergovernmental dialog in energy matters. It promotes the exchange of better practices, it connects the private and public sectors, and it promotes communication on energy transition.

73 At https://www.h2chile.cl/

74 See: https://www.h2chile.cl/post/h2-chile-figura-entre-las-entidades-que-se-adjudican-fondo-europeo-de-10-millones-de-euros-de-fchju

75 Green Hydrogen: Opportunity to lead the decarbonization of Costa Rica. Published on March 15, 2021 at https://www.ariema.com/project/comienza-el-proyecto-arichile-h2-bajo-el-marco-del-programa-europeo-innowwide

76 See: https://www.energypartnership.cl/es/home/

3.4 Costa Rica

Costa Rica, as Chile, is one of the countries that have made the greatest advances in the region on the issue of green hydrogen. The strategy of Costa Rica in relation to the introduction of H_2 into its energy matrix is centered rather on its use as a key element for decarbonizing its economy. According to the IDB[77], green hydrogen represents for Costa Rica an opportunity for innovation, for infrastructure development, for new applications and the development of human capital, and it can poise the country as a pioneer of this energy vector worldwide, allowing it to develop new markets, green jobs and income for the country.

The country took its first steps on this issue in 2011, when the private company Ad Astra Rocket and the state company Refinadora Costarricense de Petróleo created an experimental hydrogen center.

Currently, in order to define with greater clarity the country's possibilities on this issue[78], the government announced a collaboration agreement for a study on the green hydrogen domestic and global market, in order to explore the possible participation of Costa Rica in that business. The study seeks to learn about the current situation of green hydrogen at the global level (players, demand projections and costs), analyzing the economic competitiveness of Costa Rican green hydrogen vis-à-vis other export markets, estimating the production potential and its future demand in the domestic market in different segments (transport, industry, conventional fuel additive, input for synthetic fuel and energy storage), as well as estimating the macroeconomic impact of the development of a possible industry of this type in the country.

For its accomplishment, the Inter-American Development Bank, its innovation laboratory and Energy Division will collaborate on the CRUSA Foundation at the request of the Ministry of the Environment and Energy (Minae). Additionally[79], the Government of Costa Rica, through the Ministry of the Environment and Energy is working with the IDB in order to craft the National Hydrogen Strategy and Road-

77 See https://blogs.iadb.org/energia/es/hidrogeno-verde-oportunidad-para-liderar-la-descarbonizacion-de-costa-rica/

78 Costa Rica will study the potential for producing green hydrogen. Published on February 5, 2021, at https://delfino.cr/2021/02/costa-rica-estudiara-potencial-para-producir-hidrogeno-verde

79 Green hydrogen: An opportunity to lead the decarbonization of Costa Rica. Published on March 15, 2021. At https://blogs.iadb.org/energia/es/hidrogeno-verde-oportunidad-para-liderar-la-descarbonizacion-de-costa-rica/

map, as a coordination tool between the interested parties from the domestic and international public and private sectors, and also to come to an agreement on the objectives, responsibilities, barriers and incentives to be implemented.

The greatest advantage of Costa Rica in this field is its stern commitment to carbon neutrality, an issue that has transcended governments and has become one of its main characteristics.

The greatest advantage of Costa Rica in this field is its stern commitment to carbon neutrality, an issue that has transcended governments and has become one of its main characteristics. In 2007, it committed to the voluntary and aspirational goal to achieve it in the year 2021. Five year later, in 2012, the country made official the first version of its Carbon Neutrality Country Program (PCN). With the signature of the Paris Agreement in 2015, it reaffirmed its commitments and proposed trajectories to reach its objectives by 2021, 2030, 2050 and 2100. Within this framework, it sought to align the instrument Carbon Neutrality Country Program with the climate policies and published in May 2018 the Executive Decree Nº 41122-MINAE, which made official the creation of the Carbon Neutrality Country Program 2.0 (PPCN 2.0), which is currently framed within the National Decarbonization Plan of Costa Rica (Euroclima Program, Ministry of the Environment and Energy, 2019)[80].

The PCN 2.0, constitutes a public instrument that seeks to involve the private sector in the climate policies, as it allows, on the one hand, to generate a registry of emissions and reductions of greenhouse effect gases, and, on the other hand, it generates a mechanism of incentives toward the companies that seek to associate their activities with an environmental certification.

Its electric matrix also plays in its favor. It is made up almost entirely of renewable resources: water, wind, geothermal, biomass and solar. This combination

80 Euroclima Program, Ministry of the Environment and Energy, 2019. Costa Rica: Carbon Neutrality Country Program 2.0 – Organizational Category, Case Study. Available at https://ledslac.org/wp-content/uploads/2020/05/EdC-Carbono-Neutralidad-Costa-Rica-ene20_mod.pdf

has allowed Costa Rica to surpass 98% of renewable generation in its National Electric System (SEN) [81]. According to the Electric Generation Expansion Plan, PEG 2018-2034, as of late 2017 through 2034, the SEN will add to its installed capacity 653 megawatts, of which 280 would correspond to wind farms, 165 to geothermal, 161 to solar and 47 to hydroelectric. The capacity of thermal backup will not be expanded (ICE, 2019). In 2020, the National Electric System (SEN) of Costa Rica added the sixth consecutive year with more than 98% of renewable generation. Hydroelectric energy continues to be the main source within the electric matrix, with a participation of almost 72%. The second one is geothermal, with 15%, followed by wind, with 12,4%. For its part, biomass and solar contribute 0,6%[82].

The wind potential of Costa Rica, with a plant factor greater than 30%, reaches 2.400 MW of installable capacity, with an annual energy production on the order of 6.700 GWh (ICE, 2019).

The incorporation of new technologies, the change in consumption patterns, the distributed generation, the energy efficiency policies, the migration of the manufacture process industry to services and the economic contraction, have reduced the growth of the electric demand in the country. In the next two years and without affecting the reliability of the system, this condition will allow the decommissioning of two thermal plants -Barranca and San Antonio-, which have been operating for more than 40 years.

In 2018, the Inter-institutional Action Plan to Promote the Use of Hydrogen in the Transport Sector was published. It was crafted by the Hydrogen Commission, as a response to Presidential Directive N° 002-MINAE[83] (of May 2018). Within the framework of this directive, in the same year, the Hydrogen Commission was created with the responsibility of crafting an action plan for hydrogen, considering the experience of the field of action of each of the institutions that comprise the Commission within this context (Hydrogen Commission, 2018).

The formulation of the Action Plan is one more step for the materialization of the country's commitment to advance toward the decarbonization of its economy, according to the provisions contained in the National Strategy on Climate Change (ENCC) and in the Nationally Determined Contribution of Costa Rica. It is also part of the VII National Energy Plan (MINAE, 2015), in the pillars "toward a more environment-friendly vehicle fleet" and "on the road to cleaner fuels".

81 Presidency of the Republic, 2018. Costa Rica guarantees the future of its renewable electric matrix. At https://www.presidencia.go.cr/comunicados/2018/11/costa-rica-garantiza-futuro-de-su-matriz-electrica-renovable/

82 Costa Rica adds its sixth consecutive year with more than 98% of renewable electric generation. Published on January 21, 2021 at https://elperiodicodelaenergia.com/costa-rica-suma-su-sexto-ano-consecutivo-con-mas-de-98-de-generacion-electrica-renovable/

83 Ministry of the Environment and Energy.

It is also within the framework of the provisions contained in the National Development Plan (PND) 2015-2018, which seeks to promote actions for the reduction of emissions in key sectors such as transport, energy, agriculture and solid waste, in order to catalyze the transformation process toward a low-emissions development and the country's goal of carbon neutrality (MIDEPLAN, 2019). To that effect, the evaluation of the introduction of energy alternatives such as hydrogen in this sector is a response to the provisions contained in the PND, which posits, moreover, the development of strategies to continue diversifying the national energy matrix with sustainable, alternative and environment-friendly energies.

Specifically, within the Costa Rican public policies, hydrogen is considered by the National Decarbonization Plan 2018-2050 (Government of Costa Rica, 2018) as an alternative for the decarbonization of the economy. In it, the design and officialization of a roadmap for the consolidation of the Hydrogen Cluster, was established among the sort-, medium- and long-term actions of change.

The actions proposed by the Inter-Institutional Action Plan to Promote the Use of Hydrogen in the Transport Sector also contribute to materialize the provisions contained in the National Development and Public Investment Plan of the Bicentennial 2019-2022 (MIDEPLAN, 2018), which, in order to achieve the country's decarbonization of the economy in the year 2050, defined that, among the "strategic areas of presidential articulation" within the sector of infrastructure, transport and territorial organization, "we shall promote the use of alternative fuels, the change in the energy model and the improvement of consumption patterns, in order to propitiate the transition toward a less contaminating transport". As a goal, by the year 2022, fossil fuels should include 8% of the renewable components. The PND contemplates annual advances as of 2019, with the inclusion of 2,5%, in 2020 and of 5% in 2021 and, for 2022 reaching the 8% agreed.

In order to decarbonize the transport sector, the PND 2019-2022 posits to "build a national infrastructure of electric recharge centers, increasing the electric vehicle fleet and promoting the studies on low-emission fuels".

From the normative standpoint, there is a legal loophole in relation with the regulation of the commercialization of hydrogen as a "product" or fuel, in order that the Regulating Authority of Public Services (ARESEP) may develop its competencies of regulation, oversight, and price-setting, and another one related to the regulation of storage and transport of this type of fuel. However, the Costa Rican Institute of Electricity (ICE) does not require any type of concession or additional authorization in order to research, produce and commercialize hydrogen. This, given that article 5 of Law No. 7593[84], which does not distinguish the source for the generation of energy in order to consider this service of a public nature, so the generation of energy from hydrogen is not only contemplated in said legal norm as a public service, but ARESEP does not require other legal authorization for regulating and overseeing said service of “generation”, save for the sublegal normative that regulates technical aspects, as well as price-related, quality, safety, and other aspects. Thus, ICE is authorized as “legal delegate operator” for the commercialization of hydrogen:

- As a “product” to be used as fuel, for the transport subsector, for which it is authorized to establish alliances with public or private, domestic or foreign entities, such as RECOPE.
- As electricity generated from hydrogen as a supply.

Through the Institute of Technical Norms of Costa Rica (INTECO), the National Hydrogen Technical Committee was created for the adaptation of the technical international norms and standards used for the design of generation plants, storage, transport and distribution of green hydrogen.

84 Available at http://www.pgrweb.go.cr/scij/Busqueda/Normativa/Normas/nrm_texto_completo.aspx?param1=NRTC&nValor1=1&nValor2=26314&nValor3=27845&strTipM=TC

Current situation: current initiatives and initiatives being developed

In October 2019, the Non-reimbursable Technical Cooperation Agreement "Road to Decarbonization: Promoting the Hydrogen Economy in Costa Rica"[85], was signed. It set the basis for the formalization of the Hydrogen Alliance for developing the ecosystem for Costa Rican transport. The document was signed by the Inter-American Development Bank (IDB Lab) and the Costa Rica – United States Foundation for Cooperation (CRUSA), and has Ad Astra Rocket Company (Costa Rica)[86] as technical partner.

The main objective of the Alliance, which has 20 partners, is to become a mechanism for coordinating the ecosystem and positioning itself as a facilitating agent for the energy transition, as well as promoting schemes to provide support to the sector and to promote the adoption of public policies. As an organization, it will seek technical high-level advice for quantifying the impacts and benefits of hydrogen in the country, as well as crafting proposals for regulatory frameworks that allow the development of the hydrogen market.

It seeks that hydrogen, as a source of energy, be:

- 100% fully renewable
- 100% accessible to everyone
- 100% planet-friendly

Costa Rica[87] was elected the first Latin American country for conducting environmental tests with the Toyota Mirai. For this process, the Toyota Motor Corporation will deliver to Grupo Purdy Motor three Toyota Mirai and to the company Ad Astra Rocket, in order to test the hydrogen that has been developed by a national scientist (Dr. Franklin Chang), its owner. Ad Astra Rocket is a national company, a pioneer in the development of green hydrogen technologies for electric transport and energy applications, located in Liberia, in the Province of Guanacaste.

85 Within the framework of the IDB Lab project, ATN/ME-16972

86 Alliance for Hydrogen will promote technological alternatives for the decarbonization of the Costa Rican economy. Published in August 2019, at https://crusa.cr/alianza-por-el-hidrogeno-promovera-alternativas-tecnologicas-para-la-des-carbonizacion-de-la-economia-costarricense/

87 Costa Rica was elected the first Latin American country for conducting environmental tests with the Toyota Mirai. At https://www.toyotacr.com/blog/toyota-mirai-en-costa-rica

The Costa Rican Institute of Electricity (ICE) started the stage of research for producing and utilizing hydrogen as a vector of energy generated with renewable electricity. In a first stage, ICE will participate in the identification of business cases that imply the manufacture of H_2. As a part of the operation, the Institute signed agreements in collaboration with Siemens and with the national company Ad Astra Rocket (Library of the National Congress of Chile, 2020).

3.5 Mexico

In spite of the fact that, like other Latin American countries, Mexico has a great potential for production and, moreover, due to the size of its market for the consumption of green H_2, the topic still does not permeate the public policies as there are only a few initiatives likely to develop this new source of energy and which are linked to the private sector. The country committed to achieving carbon neutrality in 2050. However, it has not presented publicly a plan for reaching that goal and, within the framework of its energy policies, it considers the gas as a transition fuel.

For the electric sector, specifically, the Mexican NDC established as a goal to reach 35% of clean energies by 2024, and 43% by 2030; and the substitution of fuels by natural gas (INECC, 2018).

As in Brazil and Argentina, Mexico also has an important internal market, is very close to one of the great consumers worldwide, the United States, and has a significant grid of gas pipelines, which is considered to be an advantage for producing, consuming and exporting H_2. This grid allows to transport gas throughout the country, to transport its main consumer centers and to access its most important maritime ports in both oceans (Atlantic and Pacific).

In the country there is currently no institutional or legal framework designed to regulate the use or leverage of hydrogen as a fuel, inasmuch as, unlike hydrogen carbides, this gas is not contemplated within the description of natural resources or of assets of the nation indicated in Article 27 of the Political Constitution of the United States of Mexico (Estrada et al, 2020).

Without prejudice to the above, the third paragraph of said constitutional precept indicates the possibility that the nation may establish conditions and limitations for the appropriation of any natural resource. That is to say, that The nation shall have at all times the right to impose on private property the modalities dictated by the public interest, as well as the right to regulate, for the social benefit, the utilization of the natural elements liable to be appropriated, in order to make an equitable distribution of the public wealth, to ensure its conservation, to achieve the balanced development of the country and the improvement of the living conditions of the rural and urban population.

According to experts, this opens the possibility of designing a legal framework and a public policy that overcomes and leaves behind the debates that involve the use and destination of the renewable and non-renewable natural resources. It is expected that these conditions will allow the Mexican state to advance more rapidly in the regulation of H_2 as a fuel, and have a legal and regulatory framework that recognizes its potential and allows to establish a flexible path to its utilization. From the regulatory standpoint, moreover, it will be necessary to create the normativity in terms of ad hoc industrial safety, for transport activities, hydrogen storage and distribution and, possibly, the creation of standards and a homogenous normativity for its exploitation (Estrada et al, 2020).

As in Brazil and Argentina, Mexico also has an important internal market, is very close to one of the great consumers worldwide, the United States, and has a significant grid of gas pipelines, which is considered to be an advantage for producing, consuming and exporting H_2.

Within the current energy regulatory framework, green hydrogen is mentioned in the Transition Strategy to Promote the Use of Cleaner Fuels and Technologies[88], in the Energy Sector Program[89] and in the recently launched National Electricity System Development Program (Prodesen) 2020-2034. The information published in these documents on H_2 is very specific and limited, and requires the development of more instruments for its implementation.

The Transition Strategy to Promote the Use of Cleaner Fuels and Technologies only mentions gassing for the production of hydrogen as an efficient technology in the utilization of bioenergy. While the Energy Sector Program 2020-2024 highlights the option of exploring its utilization, without any further mention of the issue in the rest of the document.

88 Available at https://www.dof.gob.mx/nota_detalle.php?codigo=5585823&fecha=07/02/2020 and https://www.dof.gob.mx/nota_detalle.php?codigo=5596374&fecha=08/07/2020

89 At https://h2lac.org/mexico/

The National Electricity System Development Program (Prodesen) 2020-2034, published in February 2021, does not contemplate promoting new projects for renewable energy (public or private) for the rest of the administration. This would only be done as of 2025 and, therefore, in the short term, green hydrogen is not included as an alternative fuel.

Specifically, chapter 6 of the Prodesen, which deals with the Indicative Program for the Installation and Removal of Power Plants (PIIRCE), establishes that, for the short and mid-term, 2020-2024, the only projects that will be considered are those that have interconnection contracts, and those that are contemplated as strategic for achieving the objectives of the national strategic policy. Only after 2025 will there be a space for projects of flexible generation and clean energies. (SENER, 2021).

In México, between the year 2017 and October 31, 2020, renewable energies grew by 34%, with a spectacular performance of photovoltaic generation (PV). It was multiplied by 35, while wind generation only doubled, which allows us to see the great possibilities that the country has for developing green hydrogen projects.

The Law on the Energy Transition (LTE[90]), establishes that: "The Energy Secretariat shall set as a goal a minimum participation of clean energies in the generation of clean energy by 25% by the year 2018, by 30% by 2021 and by 35% by 2024". By October of the year 2020, net generation with clean energies (renewable and non-renewable) represented 25,5% of the total generated; a proportion that should have been reached in 2018 and, therefore, the country will have to make significant efforts to meet the goals proposed in the LTE. But, the proposals from the Prodesan may delay even more this process. Between November 2020 and December 2024, an incorporation of the capacity to be installed of 13.677 MW into the national transmission network (RNT) is estimated. If the photovoltaic distributed generation (GD-FV) is included, then 16.697 MW could be reached.

The Prodesan expects that the emerging technologies, such as the change of turbines with natural gas fuel to green hydrogen, the incorporation of storage systems, the technology of solar concentration, ocean energy, among others, whose trend is toward reducing its capital costs, operation and maintenance, will all have in the next five years, and in the next decades, a greater incorporation for changing the energy matrix and the reduction of the use of fossil fuels. Under these premises, it estimates that in the 2025-2034 period, the matrix will be comprised, for the most part, of clean sources, and 1,3% of the installed capacity could be generated with

90 Law on the Energy Transition, Official Gazette of the Federation, December 24, 2015. At: http://www.diputados.gob.mx/LeyesBiblio/pdf/LTE.pdf

green hydrogen in combined-cycle plants. In this period, it estimates that 29.889 MW will be incorporated into the installed capacity of the RNT, and if the GD-FV is included, the amount could reach 38.292 MW. 77% of it would correspond to clean energies. If GD-FV is included in the figure, this proportion would reach 82%. In this period of the PIIRCE 2020-2034, the storage systems were not taken into account, which must be considered in future power plants for the incorporation of their clean energies, with solar and wind energy as the primary source.

The production of hydrogen in Mexico before the Energy Reform published in 2013 was entirely destined to the oil industry, its greatest consumer. Until that date, Petróleos Mexicanos (PEMEX) had the monopoly in this market, and as it was the only producer, it demanded up to 96% of the production for its self-consumption in the National Refining System (SNR) (PEMEX, Corporate, 2018). The SNR is formed by six refineries whose total installed capacity is of 1,6 million barrels of oil per day (PEMEX, 2021). The production of hydrogen in the plants located in these refineries is exclusively for self-consumption. In 2016, said plants produced, as a whole, 248,8 million standard cubic feet (SCF) of hydrogen per day, equivalent to 653 thousand tons per day[91] (PEMEX, Corporate, 2018).

The energy reform established conditions for the utilization of new business opportunities that allow to adopt better production practices, among others, alliances with specialized companies and the subcontracting of some services in the refineries, such as hydrogen or electricity. Within this framework, and based on the 2017-2021 Business Plan and the financial situation that PEMEX was going through, the company set out to address the hydrogen requirement through the supply from a commercial provider, as these companies ensured a lower supply cost than that incurred by Pemex Transformación Industrial (P-TRI). It has the technical and financial capacity to operate and maintain hydrogen plants, guaranteeing the supply of hydrogen and steam with the quality and conditions required by P-TRI (PEMEX Corporate, 2018). P-TRI is the only company in Mexico that refines oil. PEMEX is the only national company that produces ammonia (PEMEX, 2021).

It is worth underscoring the fact that the intention of subcontracting the production and supply of H_2, sought, fundamentally, to free financial resources in order to meet the main objectives of the company: the production of gasoline and intermediate distillates in the refineries, among others.

91 1 PCS of H2= 0,002623 kg

This vision is being further reinforced in the National Development Plan 2019-2024 (Presidency of the Republic, 2019), Published in the Official Gazette in 2019, which posits, in its Point 3. Economy, in the framework of the "Rescue of the energy sector", that "a purpose of strategic importance for this administration is the rescue of PEMEX and the CFE, in order that they may operate again as levers of the national development". "In this spirit, it is a priority to rehabilitate the existing refineries, which are in a deplorable situation of abandonment and looting, the construction of a new refinery and the modernization of the electricity-generating installations owned by the State, particularly hydroelectric, some of which operate with 50-year-old machinery and produce, in general, way below their capacity". Both companies will receive extraordinary resources for the modernization of their respective infrastructures and their fiscal loads will be reviewed. And "we shall seek the rehabilitation of the production plants of fertilizers in order to provide support to agricultural producers".

Through PEMEX, Mexico currently has an infrastructure of transport by ducts of crude, gas and poly-ducts, of 17 thousand kilometers, which make up 10 Systems. Of these, eight correspond to the transport of petroleum. It also has 10 LPG terminals. In 2020, the level of utilization of this infrastructure was significantly reduced, due to the lower availability of gas in the marine regions and the lower demand for crude from the SNR (PEMEX, 2021).

But the trend of decreasing use of the infrastructure, both for processing and transport has already been showing since 2013. This, due to the lesser production from the maturity of the main production fields in the country and, at the same time, the growth of imports, both of gas and other derivatives of oil for supplying the internal consumption. In the case of NG, in the last three years the utilization index has remained at levels close to 50% (PEMEX, 2021).

The energy reform established conditions for the utilization of new business opportunities that allow to adopt better production practices, among others, alliances with specialized companies and the subcontracting of some services in the refineries [...]

One must keep in mind that the use of ducts has also suffered reductions due to other factors: in Mexico the theft of fuels from pipelines that are vandalized for that purpose is still a common practice. Within the framework of the strategy to fight the theft of fuels that was implemented by the government, this has caused the transport to be carried out with other means, such as road transport, as a way of ensuring the distribution of gasoline. In other words, if, on the one hand, it would be possible to transport other fuels, such as hydrogen, through the pipeline system already existing in the country, on the other hand, the theft and vandalism, if not contained, hinder considerably the use of that infrastructure, whose existence could make significantly cheaper the end-cost of hydrogen.

But if, from the Federation, much advancement in terms of green H_2 is not envisaged, some Mexican States have started to take initiatives. According to the director of institutional liaison of the Energy Agency of the State of Puebla, the inclusion of hydrogen as a fuel in the Prodesan is appreciated. She mentions that Agency has already had talks with companies in Spain or Chile, including the Ministry of Energy of this country[92] and that there would be a possibility to sign an agreement for exchanging knowledge and good practices related to green hydrogen in order to know the possibilities of developing it in Puebla through a state policy. This would be, according to the same source, a way to seek, from different fronts, putting on the table green hydrogen at the federal level.

The issue of Hydrogen has been addressed on different opportunities in the country. One of the earliest initiatives is the foundation of the Mexican Hydrogen Society (SMH) in 1999 by a group of researchers, academics and entrepreneurs, with the objective of promoting research, development, the training of human resources, as well as the establishment of safety norms for the use of hydrogen as a clean energy. Its greatest conquest, was, in 2014, reaching the Senate and the Chamber of Deputies, and succeeding in having hydrogen appear in the corresponding legislation as an energy vector and as an important aspect in the use of alternative sources.

The National Hydrogen Plan (PNH) was another initiative of the SMH, whose purpose it is to identify technologies, products and key markets for the development of hydrogen as a fuel and source of sustainable energy in Mexico, through research, training of specialized human resources, transfer of technology, production of goods, services and applications in the production sector. The PNH also represents a support tool for recognizing possible obstacles for the development

92 For the first time, green hydrogen was contemplated in Mexico's energy policy. Published on February 5, 2021, at https://www.energiaestrategica.com/por-primera-vez-se-contemplo-al-hidrogeno-verde-en-la-politica-energetica-de-mexico/

of hydrogen in the country and measures to overcome them. With this project, the SMH sought to apply effectively all of the technological research and development related to the issue in order to offer society an alternative in renewable energies.

The general objective of the National Hydrogen Plan was to offer a vision of the present and the future of the utilization of hydrogen as an energy vector. This, through an evaluation of the pillars of research, human resources, infrastructure and the specialized personnel training programs that Mexico has, as well as the opportunities for research, development and the application of the hydrogen technologies for the benefit of society. The PNH is still in force, and although it has not permeated the state sector, the SMH estimates that the document can be a significant contribution and a point of departure for when Mexico decides to develop strategic initiatives focused on H_2.

Another important initiative that sought to position hydrogen in the country was AERI-Hidrógeno (AERI-H_2). It was born within the framework of the Strategic Alliances and Innovation Networks (AERIs), created by the National Council of Science and Technology (CONACYT) through the sub-Program AVANCE, whose purpose was to provide support especially to networks and alliances between academia and private industry in various priority areas nationwide. The objective of AERI-Hidrógeno was to be a path for promoting the liaising and training of high-standard resources focused on the development and exploitation of energies derived from hydrogen. Within the framework of this sub-program, the Universidad Nacional Autónoma de México (UNAM), through its Engineering Department and the Engineering Academy, started –in March 2003– the formation of the National Hydrogen Network (RNH_2), which grouped the main organization, centers and specialized academic institutes of the country, aside from companies, governmental organizations and representatives from the private business sector. Its objective was to promote in the Mexican territory the incorporation of hydrogen as an energy vector to achieve the transition toward an economy supported by clean and sustainable energies through production, research, technological and commercialization development projects. CONACYT was the executing unit of the Special Program of Science and Technology 2001-2006 (PECYT), and the AVANCE Program[93] was one of its components.

93 AVANCE Program: It consisted, basically, in contributions through capital, credit and training to promote the generation, or, otherwise, the consolidation of businesses dedicated to the exploitation of scientific discoveries, innovation, research and technological developments. This program seeks to promote businesses with a "high added value", making them competitive and likely to receive investments, in order to have scientists and technologists being incorporated into the business sector. See: http://archivos.diputados.gob.mx/Centros_Estudio/Cesop/Comisiones/3_cyt.htm

In February 2012, the Mexican Hydrogen Association (AMH) was launched. It is a group of 31 founding partner companies and local and international strategic allies, such as the Energy Agency of the states of Campeche, Hidalgo and Puebla, the Energy Commission of Tamaulipas, the Energy Clusters of Coahuila, Nuevo León and Sonora, the Chilean Hydrogen Association (H_2 Chile) and the Mexican Hydrogen Society.

Its founder stated in an interview[94], that it is necessary to work on a national hydrogen strategy. On another occasion[95], he stated that the authorities must turn to see hydrogen, especially green hydrogen, for its large-scale production and thus establish a national planning: "the issue of hydrogen is in a gray zone. We will have to work on some specific regulation. We must be careful not to over-regulate something when it is not necessary, but we must put the issue on the table with the authorities". Previously[96], he had declared that it is still necessary to make diagnoses in an organized manner.

94 In order to take advantage of the potential in México, they see as necessary the national hydrogen strategy. Published on December 30, 2020, at https://www.milenio.com/negocios/ven-necesaria-estrategia-nacional-hidrogeno-mexico

95 Note published in energíahoy, on February 17, 2021 at https://energiahoy.com/2020/11/10/mexico-con-oportunidad-de-producir-hidrogeno/

96 Note published in energíahoy, on November 10, 2020, and https://energiahoy.com/2020/11/10/mexico-con-oportunidad-de-producir-hidrogeno/

Current situation: current initiatives and initiatives being developed

According to the institutional website of CONACYT[97] in the case of energy technologies based on hydrogen, the companies that seek to delve into this line are few. For example, he cites the case of a Mexican company, Einnovación S.A. de C.V., which, together with the Technological Research and Development Center (CIDETEQ) and the Advanced Technology Center, Querétaro Unit (CIATEQ), both research public centers from the CONACYT are developing a hydrogen production system from water. It is a prototype of first-generation advance electrolysis called Tritón 50 (T50) for industrial applications[98].

Another initiative being developed is the project Energía Los Cabos, an electric power plant of the Renewstable® type, developed by the French company HDF Energy. The Renewstable® plants produce energy from renewable sources and have a hydrogen backup. This way, they generate a stable and continuous base electricity coming from an intermittent primary energy source (solar), at a competitive price regarding fossil energies.

The project, in the stage of technical and environmental study, has a solar farm and storage infrastructure for energy in the form of hydrogen and Li-Ion batteries in order to guarantee a stable and non-contaminant service. Energía Los Cabos will produce 22 MW during the day and 6 MW by night, and an annual production of 115 GWh, equivalent to the electric consumption of 60 thousand persons (https://www.energia-loscabos.com/proyecto).

In December 2020, GenCell Energy, GNC[99] (TASE), a manufacturer of fuel-cell energy solutions based in Israel, announced that it was selected to implement its fuel-cell backup solutions based on hydrogen for the Federal Electricity Commission (CFE), a public service company owned by the Mexican state. The company was hired to promote and maintain, for two years, 37 fuel-cells based on hydrogen for substations throughout Mexico in an agreement worth approximately 6 million dollars. According to the terms of the tender, the CFE is entitled to buy up to a total of 74 units in the same terms, thus increasing the value of the operation up to some 12 million dollars. The delivery and implementation are planned for the first semester of 2021.

97 At https://centrosconacyt.mx/

98 Mexican Green Hydrogen. At: https://centrosconacyt.mx/objeto/hidrogeno/

99 See https://www.gencellenergy.com/news/gencell-energy-selected-to-supply-resilient-long-duration-backup-power-to-cfe-mexico-in-a-deal-valued-at-us6000000/

One of the objectives of the company is to demonstrate the capabilities of the fuel-cells as backup energy units for electric systems.

The private-capital company Tarafert, producer of fertilizers, intends to start operations of a plant in the year 2023 in the State of Durango. The company joined the initiative “Mexican Green Hydrogen”[100] in order to produce green hydrogen and ammonia in the country. The initiative operates in two phases. Currently, the first one is unfolding, which is centered on the short-term conversion of the Tarafert project in Durango into green ammonia through the use of green hydrogen and renewable energy as the raw material. The objective of the second phase is the development of a project dedicated to green hydrogen and ammonia in Mexico.

The site where Tarafert is building its plant has access to solar and wind resources. It is estimated that the implementation of phase one will result in a reduction of CO_2 emissions of up to 1 million tons per year.

In the case of this initiative, it is important to consider the proviso that, given that the Mexican Green Hydrogen website does not publish much detail, considering it effectively among the initiatives being developed in México depends on its future behavior and on the corresponding availability of information. For now, it is only cited as a possibility.

Moreover, the Mexican Green Hydrogen and Tarafert are executing the feasibility stage for the dedicated installation of last-generation green hydrogen and ammonia at a global scale. Together with the local and federal governments, agencies, renewable-energy companies and local stakeholders, they are in agreement with the information published on their website, identifying the most adequate strategy.

100 http://tarafertproject.com/mexican-green-hydrogen/

04 Opportunities and challenges for implementing an economy for green H_2

Green hydrogen has stood out as a business alternative and one more way of reducing greenhouse effect gasses. In some countries it is considered as an important element for meeting the goals of carbon neutrality committed to internally and internationally. These commitments, though they are considered to be a great strength and triggers for opportunities, in order for these to materialize, they must be integrated into the respective development models as one more way to guarantee their continuity. Furthermore, these models must take into account that the production process of this gas is highly demanding in energy, which can generate competition among different production sectors and that their use is not free of risks. Thus, formalizing H_2 within the political and legal framework comprising all of its dimensions, it increases trust and reduces the risks that the issue may lose strength, and that the investments and the positive results that their use is expected to produce could be devalued and weakened. Ensuring and maintaining credibility is a key factor, especially when one seeks to delve into new business fields[101] and when the potential market can be very competitive.

From the five countries analyzed, Chile and Costa Rica declared formally their intention to reach carbon neutrality in 2050 and have advanced consistently in the institutionalization of said intention. Both consider that H_2 has the potential to decarbonize their economies and that it represents an opportunity for developing a new business, for which they have countless advantages. Chile published the Hydrogen Strategy, while Costa Rica is working to detect the potentials of green H_2 in the country in the short term.

101 The current risk rating, according to the indices by Moody's, S&P and Fitch (https://datosmacro.expansion.com/ratings):
Argentina: CCC (substantial risk)
Brazil: BB- (speculative non-investment rating)
Chile: A (mid-high rating)
Costa Rica: B (highly speculative)
Mexico: BBB (mid-low rating)

In Brazil, although carbon neutrality is only a voluntary indication in its updated NDC, hydrogen is part of the Brazilian hydrogen strategy defined in the National Energy Plan 2050 approved in December 2020. It is considered to be a disruptive technology and an element of interest in the context of the decarbonization of the energy matrix.

Mexico also committed to achieving carbon neutrality in 2050. However, it has not presented publicly a plan for achieving this goal and has postponed the entry of new projects for the production of clean energies until the year 2024, which would postpone the introduction of green H_2 into its energy matrix. Argentina, though it considers carbon neutrality attainable by 2050, it has not presented a formal proposal in that direction either.

Generally speaking, in order for these countries to advance most rapidly and deliver the institutional security required by the development of the new source of energy, an essential aspect is that hydrogen must be regulated as such, and the normativity to be designed must recognize and explicate the environmental risks associated with its production, uses, storage and transport. Specifically, it will be necessary to create a normative body on matters of ad hoc industrial and environmental security, and homogenous standards that allows its transit among the countries and the development of regional economies.

This will demand an ample and deep technical knowledge, aside from legal and fiscal, which, as a whole, may promote and generate an environment propitious for the production, use and commercialization of H_2. It is probable that not many countries in the region have this installed capacity in their legislative structures, or that concentrate their attention in this field in the short term. This can delay its development and affect its competitiveness in this field.

Below, we comment, according to the enabling conditions, on the challenges that must be confronted by each one of the countries analyzed, depending on the progress of these enablers, as per the criteria defined in this study, and presented in chart 2. The enablers considered are the aspects that are deemed to be facilitators for the implementation of a green H_2 economy in the short term and in the five countries. As for the classification criteria, High carries the highest score, while Low includes zero and low presence. This is an indicative exercise that only seeks to illustrate and contrast the current condition of the countries in relation to the enablers which it estimates that will allow it to advance in the implementation of the hydrogen economy in a sustained manner, and that several of them have budgeted to be carried out in a close term in time. Thus, the country that would present the best conditions for advancing in the development of a hydrogen economy in the short term would be Brazil, followed by Chile and Costa Rica. A little farther behind are Mexico and Argentina. Each one of them is commented in this order.

These results do not contradict the statements above regarding the progress of the countries, where Chile and Costa Rica stand out, essentially, because said progress is reflected in the consistency and rapidity with which they formalized hydrogen within their political frameworks as a clean energy alternative and as a way of meeting their emissions commitments and of carbon neutrality of their economies.

Table 2. Current condition regarding the enablers for the implementation of a green H2 economy

Indicators	Argentina				Brasil				Costa Rica				Chile				México			
	L	M	M-H	H	L	M	M-H	H	L	M	M-H	H	L	M	M-H	H	L	M	M-H	H
Institutionality	1				1							4				4	1			
Laws / normative		2			1				1					2			1			
R&D&D	1						3				3			2			1			
Commitment to carbon neutrality	1				1	1						4				4	1			
Clean electric matrix	1							4				4		2			1			
Non - conventional renewable energies in the electric matrix		2				2			1						3			2		
Average plant factor				4			3			2					3			2		
Internal market		2						4	1					2					3	
Production infrastructure		2			1				1				1				1			
Transport infrastructure (ducts, ports)			3				3			2						4			3	
Short distance national consumption centers	1							4			3		1						3	
Short distance international consumption centers	1				2					2			1							4
	6	*8*	*3*	*4*	*4*	*5*	*9*	*12*	*4*	*6*	*6*	*12*	*3*	*8*	*6*	*12*	*6*	*4*	*9*	*4*
Total	*21*				*30*				*28*				*29*				*23*			
H: High = 4; M-H: Medium - High = 3; M: Medium = 2; L: Low = 1																				

Source: crafted in-house.

Chart 1, summarizes the current use that these countries give to H_2 and the potential use that they could give to this energy in the future and, below, we analyze each country based on the score obtained.

Chart 1 . Current use of H_2 and potential use of H_2 with low carbon emissions

Country	Current use	Potential use of low- carbon H_2
Argentina	Chemical industry Refining	Potential for becoming an exporter of hydrogen with low carbon emissions (blue and green) Descarbonization of the chemical industry Descarbonization of carbon
Brazil	Chemical industry Refining	Potential for becoming an exporter of hydrogen with low carbon emissions (blue and green) Descabonization of the chemical industry and refining
Chile	Chemical industry Refining	Potential for becoming an exporter of hydrogen and ammonia with low carbon emissions, mainly green Decarbonization of the mining industry, chemical industry and refining Decarbonization of transport
Costa Rica	Industry	Decarbonization of heavy transport and passenger transport
México	Refining	Decarbonization of the refining industry and transport Potential for becoming an exporter of hydrogen with low carbon emissions (mainly blue)

Source: crafted in-house based on IEA 2020b.

Brazil

Brazil's greatest advantages for implementing a green H_2 economy are its early start on the issues related to hydrogen and the successive initiatives on R&D&D, that could make the country partially or totally independent technologically, with the corresponding impacts on the end-costs that the production of this gas could have. The country has human resources and laboratories capable of dominating strategic niches and can participate in the production of components and supplies for equipment of pure generation of hydrogen or of energy, be they fuel-cells, chemical or biological processes. This is particularly important because the plant factors of Brazilian renewable energies, though high on average, are not comparable with those that could reach Chile and Argentina, and, therefore, any factor that can impact on the end-price will decide the competitiveness of each one of those countries. Another advantage of Brazil is its already clean electric matrix, as well as the dimensions of its internal market, which allow it productions at a large scale and being competitive internationally. The availability of the infrastructure and the Atlantic route that gets it closer to large consumption centers are also important advantages, as well as the existence of international companies in its territory, which produce and consume H_2, and also the existence of technology providers.

Brazil, moreover, has experience in the production of ammonia for fertilizers, in handling high-pressure compressed gases, and, as a transition stage, a potential for producing blue H_2 with biomass or biogas at competitive costs, and probably lowers than those of green H_2, even considering the values of the CAC.

Other enablers are the considerations regarding H_2 in the various public policies, which formalizes the country's intention of advancing on the issue.

Issues that the country must consider in order to make progress in including H_2 into its energy matrix and take advantage of the momentum created around green H_2:

- The national norms and patterns related to the utilization of hydrogen as energy are insufficient;
- There is no formal commitment to the decarbonization of the economy. In the NDC, it is only indicative;
- The national market of energy hydrogen outside the industrial field is not large, and this is not expected to change in the near future;
- Deficient production chains, storage and transport: although there are important advances in the creation of national technology, it competes with the state-of-the-art international technology;
- In the transport sector, H_2 will compete with other energies such as biofuels and electricity;
- There are great gas reserves not yet explored or exploited;
- It is a producer of black and gray H_2;
- The energy matrix is considered to be one of the most important hindrances because of the great diversity of existing clean sources and a potential competition among sectors;
- The costs of renewable energies are still high and do not compete with fossil energies;
- Studies are being developed for ethanol fuel-cells, a strong competitor of H_2;
- Regarding electricity, it is necessary to reactivate the infrastructure provision programs;

  - It is possible that when growth resumes, the country may have an important electricity deficit and resources would be needed for its expansion;

Brazil's greatest advantages for implementing a green H_2 economy are its early start on the issues related to hydrogen and the successive initiatives on R&D&D[...]

- Climate change can affect the availability of hydric resources, the greatest source of energy of the electric matrix;

- The production sectors compete for clean energies and, in the future, even more so;

- There is a lack of clear and systematic policies regarding the expansion of the offer of renewable energies and for the deployment of the use of H_2 as fuel;

- There is no support from the state for incorporating non-conventional energies into the electricity/energy matrix and the programs that existed have been waning.

Chile

Chile has in its favor the political and financial stability and the many free-trade agreements signed with different countries and with the main consumers, and the availability of port infrastructure and gas pipelines, as a product of its condition of importer of fossil fuels and gases. This condition causes it to have ample knowledge for handling different energy resources in general, including high-pressure gases. Chile, moreover, has demonstrated consistency regarding its energy policy and has made consistent progress in the cleanliness of its matrix and with the commitment to carbon neutrality assumed formally. It has a great potential related to the high plant factors, especially with wind energies, that would allow it to produce green H_2 at a very competitive level, even vis-à-vis the greater transport costs due to the location of the country in relation to the global consumer markets and to its potential production zone in the local context. Its closeness to Argentina and similarities regarding the potential for producing green H_2, rather than generating competition, ought to create synergies and the conditions for a supra-national development. In that sense, Chile's experience, due to the many international agreements that it has signed, could facilitate these processes.

In order to take advantage of the opportunities offered by green H_2, Chile must overcome some obstacles:

- Adapting and modernizing the norms that regulate H_2, throughout its lifecycle, in order to prevent the projects that are already being developed and in the portfolio;
- Even with important advances in the adoption of cleaner energy resources, the electric matrix continues to be dirty. The country is a great importer of fossil resources and a sizeable part of the electricity is still based on these fuels;

- Even having many commercial allies, the main buying markets are far away;
- Its direct competitors are Argentina, Mexico and Brazil:

  - Argentina, because it shares the high plant factors, but, at the same time the remoteness of the international markets, and, therefore, similar costs.

  - The dimensions of the internal markets of Mexico and Brazil enable them to produce on scale and to have access to the larger markets: Mexico's neighbor is the USE, and Brazil, through the Atlantic Ocean, can have direct access mainly to the European market.

- The internal market is scarcely important: therefore, it will be necessary to advance in alliances with the neighboring countries in order to generate regional markets and, at the same time, at a scale fit for competing in the large markets and with the large producers;
- The cost matrix for the production of H_2 is marked by a high technological dependency;
- The financial resources are provided mostly by the private sector.

Chile, moreover, has demonstrated consistency regarding its energy policy and has made consistent progress in the cleanliness of its matrix and with the commitment to carbon neutrality assumed formally.

Costa Rica

Probably the greatest advantage of Costa Rica for delving into the H_2 market is its stern conviction toward carbon neutrality, an issue that has transcended governments and has become one of its Main characteristics. The conviction regarding environmental issues has strengthened the national institutionality, which has been moving forward and considering new matters such as the climate change combat, for the benefit of the country. Costa Rica has an electric matrix that is essentially clean and basically hydric. But the country has been advancing in the installation of other sources, such as geothermal and wind. Given its dimensions, the production of H_2, if such were the case, would be close to the consumption centers. And if it should be imported, both Mexico and the USA, potential producers of green H_2 at affordable costs due to the dimensions of their respective internal production capacities, could be their suppliers, but at the same time, their buyers.

Some issues to be considered in order for the country to introduce H_2 into its energy matrix:

- There is a legal loophole regarding the regulation of the commercialization of hydrogen as a "product" or fuel;
- The internal market is scarcely important, so, in order to produce H_2, it would be advisable to collaborate with neighboring countries to expand the scale;
- Limitations of offer and risk of high prices. Remoteness of the more competitive markets, such as Argentina and Chile;
- High technological dependency of use and manufacture;
- The electric matrix, though it is mainly clean, its

condition of being basically hydric, in the face of climate change it could be considered at risk, so it would be necessary to accelerate and intensify the introduction of alternative sources such as wind and geothermal, which are already being implemented in the country.

The conviction regarding environmental issues has strengthened the national institutionality, which has been moving forward and considering new matters such as the climate change combat, for the benefit of the country.

Mexico

Mexico has demonstrated little interest regarding the issue of green H_2. This is explained, to a great extent, by the government's vision of considering the use of gas as a transition fuel, until the economy of the country can advance safely toward a cleaner energy matrix. This is manifest in recent public policies on energy, which do not contemplate promoting new renewable energy projects (public or private) for the rest of the administration. In 2020, 25% of the electricity produced in Mexico came from some renewable clean source. This was the goal for 2018.

This would only be done as of 2025, so, in the short term, green hydrogen was not considered as alternative fuel. This energy source is mentioned in the Transition Strategy for Promoting the Use of Cleaner Technologies and Fuels and for whose production bioenergy could be used.

Mexico, though it had committed to achieving carbon neutrality in 2050, as Argentina, it has not yet presented publicly a plan for achieving the goal. Like the other countries analyzed, it does not have an institutional or legislative framework to regulate the use or leverage of hydrogen as a fuel. Unlike hydrogen fuels, this gas is not contemplated within the description of natural resources or assets of the nation.

Like Brazil and Argentina, Mexico has a great potential for H_2 production. This, due to the great availability of non-conventional renewable energies such as wind, solar and geothermal, due to the dimensions of its internal market and the proximity to one of the largest world consumers, the USA. The country has a significant grid of gas pipelines that interconnects its main consumer centers and its most important maritime ports in both oceans (Atlantic and Pacific), and which could be enabled for the transport of H_2.

Like Brazil and Argentina, Mexico has a great potential for H_2 production. This, due to the great availability of non-conventional renewable energies such as wind, solar and geothermal, due to the dimensions of its internal market and the proximity to one of the largest world consumers, the USA.

In order to make progress, in the event that the country would have an interest in issues related to green H_2, it is important to consider:

- Public policies related to renewable energies had been erratic and dependent on each public administration;
- Carbon neutrality is an intention that has not materialized into a public policy;
- Regarding the energy matrix, the NDC contemplates the substitution of fuels by natural gas;
- The country does not have an institutional or legislative framework oriented to regulate the use or leverage of hydrogen as a fuel. This gas is not included within the description of natural resources or assets of the nation;
- In 2020, 25% of the electricity produced in Mexico came from some renewable clean source. This was the goal for 2018. By 2021, it should have reached 36%. This means that the process of cleaning the electric matrix has been slow. Therefore, the country has more possibilities to continue producing gray H_2 based on gas and, in an intermediate stage, on blue H_2, based on gas, but with CAC;
- The level of use of the infrastructure of hydrocarbon transport by ducts was significantly reduced in the last years. This is an opportunity for transporting hydrogen through the pipeline system already existing in the country, but, if theft

and vandalism, a practice that is still common, are not contained, the use of this infrastructure, whose existence could significantly cheapen the end-cost of hydrogen, would be hugely compromised.

Argentina

Argentina, like Brazil, has an early experience with the issue of hydrogen. However, with the passage of time, and although the country has promulgated what would be the only law that regulates this gas and having operational a green H_2 plant in Latin America since more than 10 years ago, currently, it has made little progress in defining an institutionality or a legal framework that can sustain the development of this energy source. The country has not presented yet a proposal that indicates its real intentions with a decarbonized development model, although the government has stated that this would be reachable by 2050.

The country presents, undoubtedly, clear advantages for the production of green H_2. The price of clean energy in Patagonia can be very low due to the high plant factors: less than 2 dollars/kg of green H_2. It has a great experience in the production of ammonia for fertilizers and in the handling of high-pressure compressed gases. It has an important internal grid of gas pipelines which reaches neighboring countries, as well as a port infrastructure, also in the Patagonian zone. Its most direct competitor is Chile, so they could be expected to develop joint capabilities and to cooperate in the development of the sector.

The current capacity of clean energy generation should reach 20% of the matrix by 2025, and this proportion is considered to be sufficient to promote the local hydrogen industry in a first stage, focused on public transport.

But, in order to become an important player in the green H_2 issue, Argentina must make progress in resolving some aspects:

- Political commitment and continuity, and guarantees as a supplier;
- The need for financial resources:

    - It is necessary to invest 12 billion dollars among wind power farms, hydrogen production plants and liquefaction plants to produce 430 thousand tons of hydrogen annually

    - The need for external financing to improve the infrastructure of transport of H_2

    - The greatest potential is in Patagonia, far from the domestic consumer market, and with insufficient infrastructure for reaching the international markets

    - The need for financing for CAC

- Blue H_2 can be produced for less than 2 dollars/kg, a value very similar to green H_2.

The current capacity of clean energy generation should reach 20% of the matrix by 2025, and this proportion is considered to be sufficient to promote the local hydrogen industry in a first stage, focused on public transport.

4.1 Proposals for positioning themselves in the green hydrogen market

In order to facilitate the adoption of this technology, according to the National Energy Agency (IEA, 2019), in the short term, with a horizon by 2030, it is necessary to have five "intelligent" political actions: (1) sending long-term goals and/or policy signs in order to promote trust among investors; (2) stimulating the commercial demand for hydrogen in multiple applications; (3) helping to mitigate the most important risks, such as the complexity of the value chain; (4) promoting R&D, demonstrative projects and the exchange of knowledge; and (5) harmonizing standards and eliminating barriers.

For the IEA, "ambitious pragmatism" will be essential for generating a drive, for providing support to the development of low-cost hydrogen with a low carbon content on a large scale, and in order to help to position it so that it is ready to compete and take advantage of the opportunities in the longer term.

Considering that each one of the countries analyzed has clear strengths and weaknesses that will set the pace for their positioning in the green H_2 market and, taking as a reference the recommendation by the AIE, some actions are proposed which would allow them to make better advances in order to enter this new market.

1

In order to **generate trust** as suppliers, it is necessary to guarantee the legal and institutional security, with long-term goals and policies that support them, and, above all, regulating H_2 as an energy source, as well as legalizing it and stopping to look for legal gaps or loopholes for introducing it into the energy matrices;

- Defining and crafting an ad hoc national normative body or updating the current one, eliminating unnecessary rules

- Homogenizing regional norms/rules: it facilitates commerce and ensures all of the links of the value chain

- Strengthening the climate and environment policies

- Formalizing carbon neutrality, where it is yet to be done. This intention and/or commitment, must materialize in a manner that is consistent with the public policies for all endeavors in development matters in each country. When the countries will measure their development, based on the growth of their economies, they must also measure it in relation to the amount of CO_2 that is disappearing from it. The strategic decisions must take into account booth indicators, not only the economic one. Thus, for example, the price-setting policies for carbon, or equivalent, will reduce the cost gap between synthetic hydrocarbons and fossil fuels and would reward and/or punish their use;

2

In order to achieve **competitive prices**, the plant factors of the clean energy sources are not the only important factors. Almost all of the countries analyzed have a high technological dependency. This is also applicable to other countries in the region. In order to overcome this deficiency that has a strong impact on the end-costs of the product, especially in the initial stages of technological adoption, local incentives must be defined, such as fiscal treatments, subsidies, insurance, guarantees and low-cost financial resources, for example, until the technology has reached its maturity and the consequent cost reductions:

- Measures that help to tilt the scale in favor of private investment when the risks are dominated by uncertain demand, a lack of familiarity and the complexity of the value chain.

3

Creating **schemes of** international **cooperation** which favor access to state-of-the-art technology at lower costs. International cooperation helps to synchronize the expansion of demand for hydrogen, to reduce the risks related to the competitive pressures for the sectors exposed to commerce and supports investment in the manufacturing capacity;

4

Stimulating the commercial **demand** for hydrogen in non-conventional applications. Four value chains offer opportunities for increasing the offer and demand of hydrogen:

i. Transforming the industrial clusters into consumption hubs and thus simulating the use of clean hydrogen. An increasing demand for low-carbon hydrogen in the main industries offers the opportunity to reduce its costs and start up new demand sources. Thus, the coastal industrial conglomerates located near the ports are particularly attractive;

ii. Utilizing the existing gas infrastructure in order to help promoting the supply of hydrogen with low carbon emissions and take full advantage of a reliable source of demand. According to the IEA (2019) a mix of 5% would create a large new demand for hydrogen and hydrogen at 100% allows for a deep reduction of emissions in the long term.

iii. Providing support to those transport options where hydrogen has more advantages. This could lead fuel-cell vehicles to be more competitive and to promote the development of the related infrastructure. The current objectives of the governments in terms of emissions would require by 2030 2,5 million fuel-cell vehicles circulating and 4.000 service stations. Such application could reduce the costs of fuel cells by 75% (IEA, 2019)

iv. Starting up the international maritime routes for hydrogen commerce. It is possible to take advantage of the lessons of the global market for LNG in this field. International hydrogen commerce must begin soon in order for it to have an impact on the world energy system (IEA, 2019).

5

Increasing the spectrum of possible **new applications** for hydrogen, as an alternative to the current fuels and supplies, or as a complement to the greater use of electricity in these applications. For example, for producing heat, iron, steel and cement, as well as electricity, hydrogen must be used in its pure form or as a hydrogen-based fuel.

6

Promoting R&D and creating networks for **disseminating** and **exchanging knowledge** and seeking, as far as possible, technological independence. The role of the state is crucial, especially in the early stages, when the successes of technological advances are uncertain.

7

Creating specific capacities: the production, transport, storage and use of hydrogen can require technologies and new high-precision products or specific materials for storage tanks or pipelines, as well as burners. This offers an opportunity for the countries to develop leadership, technical experience and new jobs in these areas, particularly when they reinforce the already existing skills and capabilities. But if these do not exist, the challenge is to create them in the shortest term possible.

8

Converting existing capabilities: some skills related to existing assets can reduce their value in a low-carbon scenario, but a large part of this value could be conserved if they are compatible with the new use of the current infrastructure. For example, some operators of natural gas networks are exploring the possibility of replacing it partially with alternatives of less CO_2 intensity, including hydrogen. Then, if hydrogen can be used in a profitable manner for reducing industrial emissions with no relocation of manufacturing, this would help to maintain the local jobs. Likewise, if CAC is used in order to reduce the intensity of CO_2 from the production of hydrogen from fossil fuels, this would allow for some fossil fuel resources to continue to be used.

The International Renewable Energy Agency (IRENA, 2020a), in a new guide for the crafting of policies around green hydrogen, underscores the progress made by Chile for the development of a national strategy on this matter, and it recommends a series of measures for promoting this resource.

The document upholds Chile's initiatives and places this Latin American country among those that have made the most progress recently on this issue. The Chilean strategy has established goals that will allow the country to become a pioneer and, at the same time, a referent in the development of a national industry and, thus, to export its experience to other regions. The key step that the country took was to define formally a strategy and to consider green H_2 as a contribution to the decarbonization of its economy.

The document indicates that green hydrogen, unlike gray and green hydrogen (based on fossils, without and with CAC, respectively) also helps to promote renewable energies in the electric matrices and the decarbonization of the energy-intensive industries. It describes the main barriers that inhibit the absorption of green hydrogen and the policies necessary to address them, and it delivers information as to how to promote the green hydrogen sector as a key enabler the energy transition at the national or regional level.


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National strategies:

Each country must define its level of ambition for hydrogen, describe the amount of support required and provide a reference regarding the development of hydrogen for private investment and financing. This process usually starts with the implementation of R&D programs for understanding the foundations of the technology in order to be able to develop future stages. Moreover, it contemplates reviewing the legal and normative framework and the technological availabilities and resources to be deployed for its implementation. A key to this pillar: Why hydrogen, why now, what for?

Political priorities:

Green hydrogen can support a wide range of end-uses. Those responsible for the formulation of policies must identify and focus on the applications that contribute the most value, especially at the start of the business. A key to this pillar: H_2 is not a full substitute to fossil fuels. Prioritizing the applications that generate the most value. Green H_2 must only be produced with the additional capacity of renewable energies.

Guarantees or certification of origin:

Carbon emissions must reflect throughout the lifecycle of hydrogen. The schemes that guarantee the origin must include clear labels for hydrogen and the products of hydrogen in order to increase consumer awareness and facilitate the incentives. A key to this pillar: H_2 molecules are all equal, regardless of their color and, therefore, it is indispensable to differentiate them through certificates.

Governance and enabling policies system:

As green hydrogen ceases to be a niche product and becomes something common, the policies that promote it must also cover its integration into the wider energy system. It is the economic policies that affect the sustainability and the pace of the transition. A key to this pillar: civil society and the industry must participate in order to maximize the benefits. Identifying economic growth opportunities and job creation. Introducing H_2 as part of energy security. Ensuring access to financing. Establishing international codes and standards. Building or reforming the infrastructure. Collecting data. Establishing research priorities. Implementing pricing schemes for carbon. Removing subsidies on fossil fuels.

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